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FLIGHT TEST EVALUATION OF AVOID II (AVIONIC OBSERVATION OF INTRUDER DANGER) COLLISION AVOIDANCE SYSTEM

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

AVOID is a candidate for a national standard collision avoidance system. A comprehensive flight and laboratory evaluation of the AVOID II version was conducted including the ability to communicate accurately and with sufficient distance to provide timely and correct advisories and maneuver commands in simulated high traffic density.

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SUMMARY

INTRODUCTION

Many systems have been advanced as potential solutions to the collision avoidance problem. Only a few of these attempts have survived critical analysis and testing. Comparative system evaluations are being conducted based on performance, cost, and size requirements.

The FAA (Federal Aviation Administration) has been directed by the U.S. Congress to report on CAS (Collision Avoidance System) progress and to arrive at a decision for a National CAS Plan. As a result of Department of Defense involvement in that decision, the Navy is evaluating the performance of some of the proposed systems. The work reported herein was sponsored by the Department of Transportation and the Department of Defense.

One of the systems being evaluated by the Navy was designed by Honeywell and is known as AVOID (Avionic Observation of Intruder Danger). This is a family of equipments which provide varying levels of protection commensurate with the performance characteristics of various types of aircraft. At present, the AVOID I and AVOID II represent the maximum and minimum equipments. The AVOID I is designed for military and air carrier aircraft which fly the civil air lanes. The AVOID II is a smaller, less costly version designed for lower performance military and civilian aircraft.

In October 1973, the FAA, Navy and the Naval Air Development Center entered into an agreement[1] for the procurement and subsequent flight testing of the AVOID I equipment. Laboratory and flight testing was completed in November 1974 and the results of these tests were reported in Report No. NADC-75056-60 of May 1975. As a result of a modification to the above agreement between the Department of the Navy and the Department of Transportation, the NAVAIRDEVCEN was funded to procure the AVOID II for flight test and analysis. The contract[2] for the purchase of two AVOID II systems and modifications to the AVOID I and the associated calibration and simulator equipments was executed in September 1974, and the AVOID II equipments were delivered in May 1975.

The AVOID II tested was an engineering prototype packaged in a 3/8 ATR short case, with the production unit to be housed in a standard 1/4 ATR short case. This report documents the flight test evaluation of the AVOID II CAS.

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[1] Interagency Agreement DOT-FA73WAI-358 Modification No. 2 Between FAA and NAVAIRDEVCEN for the Technical Evaluation and Flight Test Program of the AVOID II CAS dated

[2] NAVAIRDEVCEN Contract N62269-75-C-0149 of 13 September 1974 with Honeywell.

OBJECTIVES

The general objective of this test program was to evaluate the ability of the AVOID II to perform the collision avoidance function required by aircraft with reduced performance characteristics, and to ascertain the effectiveness of modifications to the AVOID system designed to improve performance.

SUMMARY OF RESULTS

The AVOID II provided the correct avoidance warnings to the pilot during encounters with both AVOID I and AVOID II equipped aircraft. These warnings were consistent with the system specifications for general aviation requirements.

The r-f communication range between AVOID I and AVOID II equipped aircraft was sufficient for the AVOID I generation of warnings consistent with ANTC-117 requirements. The maximum threat processing range of the AVOID II (4.2 nmi or 7.8 km) resulted in an effective protected volume around the aircraft which was a function of the closure rate between aircraft. A 40-second warning could be generated for closure rates up to 300 knots (154 m/s), and a 25-second warning for rates up to 425 knots (219 m/s).

The pilot display reliability was 99.4 percent.

The air-to-air data link established the correct relative altitude with a reliability greater than 99.5 percent of the time while operating with fruit in accordance with appendix A.

The range and range-rate accuracies (Theodolite reference) were:

Range Error (Feet)		Range Rate Error (Knots)	
Mean	Sigma	Mean	Sigma
167	120	6.6	6.6
(51 m)	(37 m)	(3.4 m/s)	(2.4 m/s)

No false alarms occurred during approximately 52 hours of flight testing and 142 hours of laboratory testing.

CONCLUSIONS

The AVOID II has the potential for performing a collision avoidance function for general aviation aircraft which is compatible with ANTC-117 requirements for a full CAS.

The communication range was more than adequate for encounters between aircraft with performance characteristics for which the AVOID II was designed. The maximum tracking range of the AVOID II did not allow threat processing of all intruders within communication range.

The display and tracking reliabilities were satisfactory. All encounters were flown in the presence of the simulated traffic environment of the Los Angeles basin in 1982 as predicted by Honeywell for the AVOID system.

The modified interrogation sequence and threat processing criteria were satisfactory. This modification combined with the new altitude scale factor (2 ns/ft.) resulted in a greatly improved air-to-air data link.

The range and range-rate accuracies were satisfactory.

The warning times were satisfactory for closure rates up to 400 knots (206 m/s). During encounters with closure rates greater than 450 knots (231 m/s), warning times of less than 25 seconds occurred.

RECOMMENDATIONS

It is recommended that the threat processing range of the AVOID II be extended in order to allow full 25-second TAU-1 commands and 40-second TAU-2 advisories for closure rates up to 550 knots (283 m/s). This would only require additional range registers since the power budget is already sufficient to provide the full warning times.

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EQUIPMENT DESCRIPTION

AVOID II CAS CONFIGURATION

The AVOID collision avoidance system developed by Honeywell operates on a cooperative basis with other aircraft. The AVOID equipments utilize a single frequency interrogator transponder pulse ranging technique. Aircraft barometric altitude is exchanged via interrogation pulse coding. The altitude information is conveyed in the spacing between the first and second pulse pair of an interrogation quad. Aircraft respond only to those interrogations which fall within a prescribed zone relative to their altitude. A single pulse is generated when the altitude interrogated is within an acceptance window established by the interrogated aircraft. The range between aircraft is determined by the transmission delay between aircraft. The closure rate is established by comparing successive range measurements (at 1/2-second time intervals) during an interrogation sequence (3-1/2 seconds). Threat status is evaluated on the basis of relative altitude and Tau (range divided by closure rate between aircraft). Threatening situations result in advisories and commands which pertain to the vertical speed of the aircraft (ie. CLIMB or DIVE commands and LIMIT VERTICAL SPEED advisories). A detailed description of the AVOID II theory of operation is contained in appendix B. Figure 1 is a block diagram showing the functional organization of the AVOID II.

The AVOID II tested was an engineering prototype packaged in a 3/8 ATR short case. An outline drawing of the AVOID II interrogator/transponder with dimensions is shown in figure 2. The AVOID II maneuver indicator is shown in figure 3. The AVOID II with dust cover removed to expose interior assembly is shown in figure 4. Construction was of a modular nature consisting of four basic functions: transmitter, receiver, power supply, and digital processor. The basic characteristics of the AVOID II tested were:

1. 3/8 ATR short package
2. Weight - 10 lb (4.5 kg)
3. Power required - (115V/400Hz) - 350 ma

   - (28VDC) - 3.0A nom/4.0A max
4. RF - dual channel, center frequency 1607.5 ± 1.5 MHz
5. Transmitter output pulses - 100 ± 20 ns wide
6. Peak RF transmitter power - 54 dbm minimum at antenna port
7. Receiver sensitivity range - -22 dbm to -68 dbm

Figure 5 is a photograph of the AVOID II together with the AVOID II maneuver indicator. The AVOID II also provides the signals necessary to operate the standard CAS/VSI indicator.

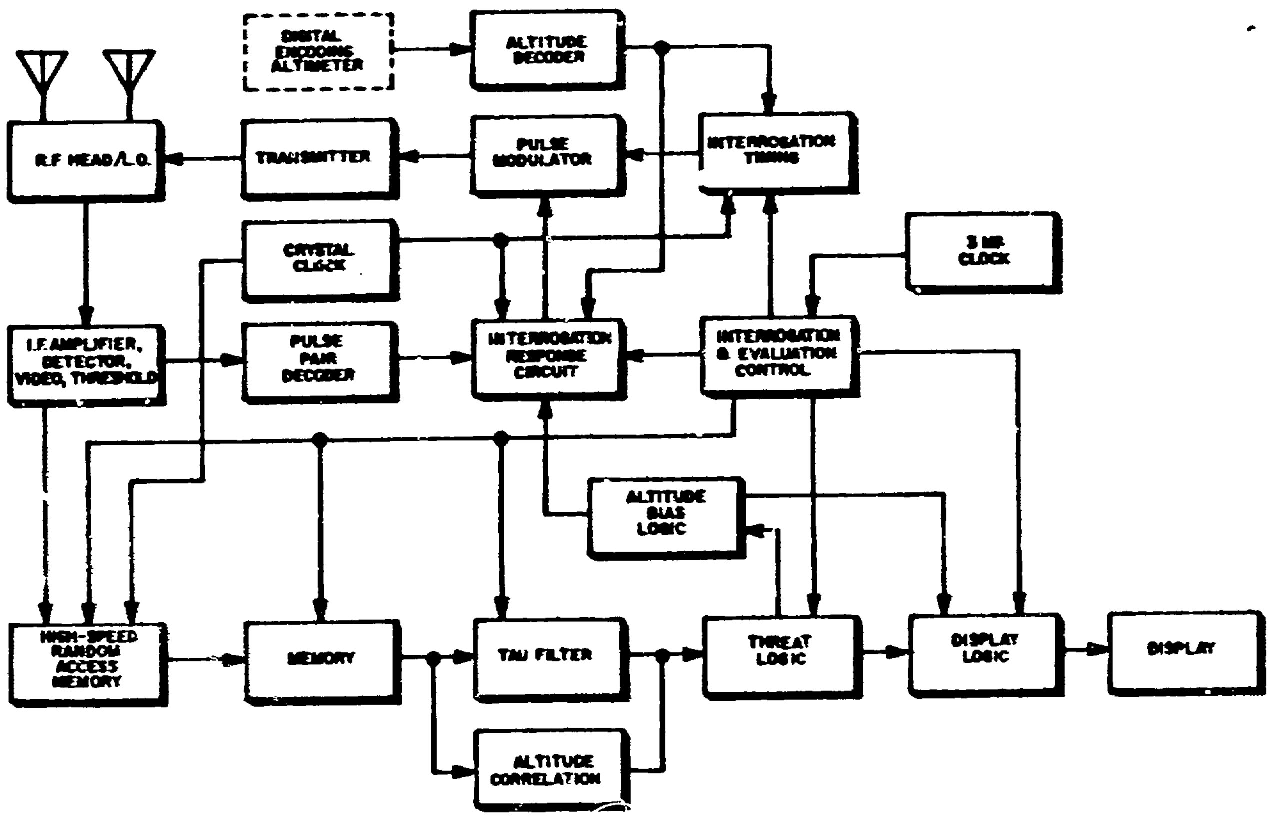


Figure 1. AVOID II Functional Block Diagram.

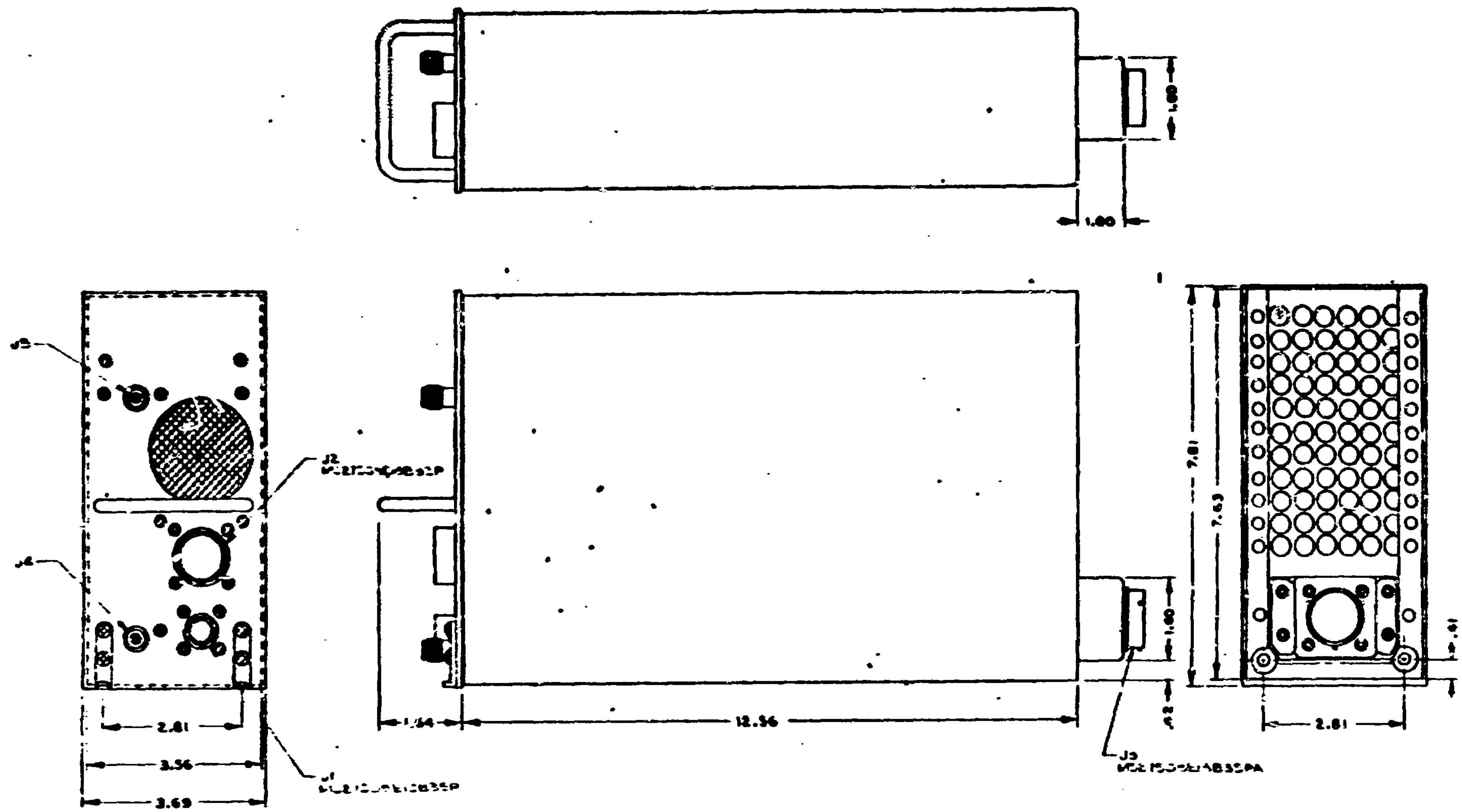


Figure 2. AVOID II Outline Drawing.

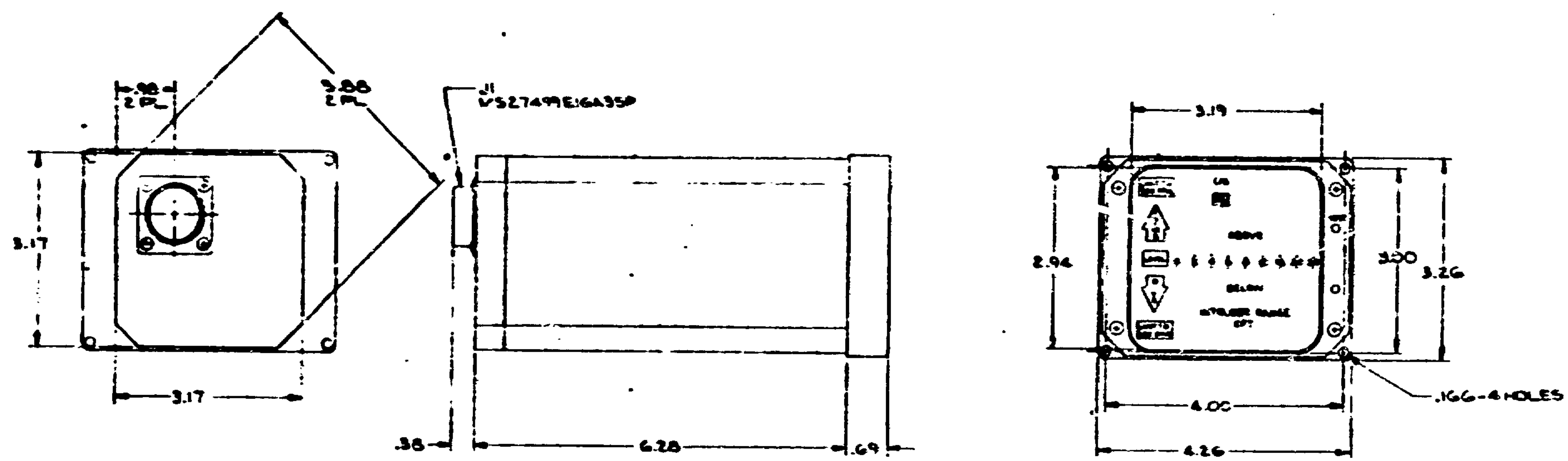


Figure 3. A[illegible]ID II Maneuver Indicator.

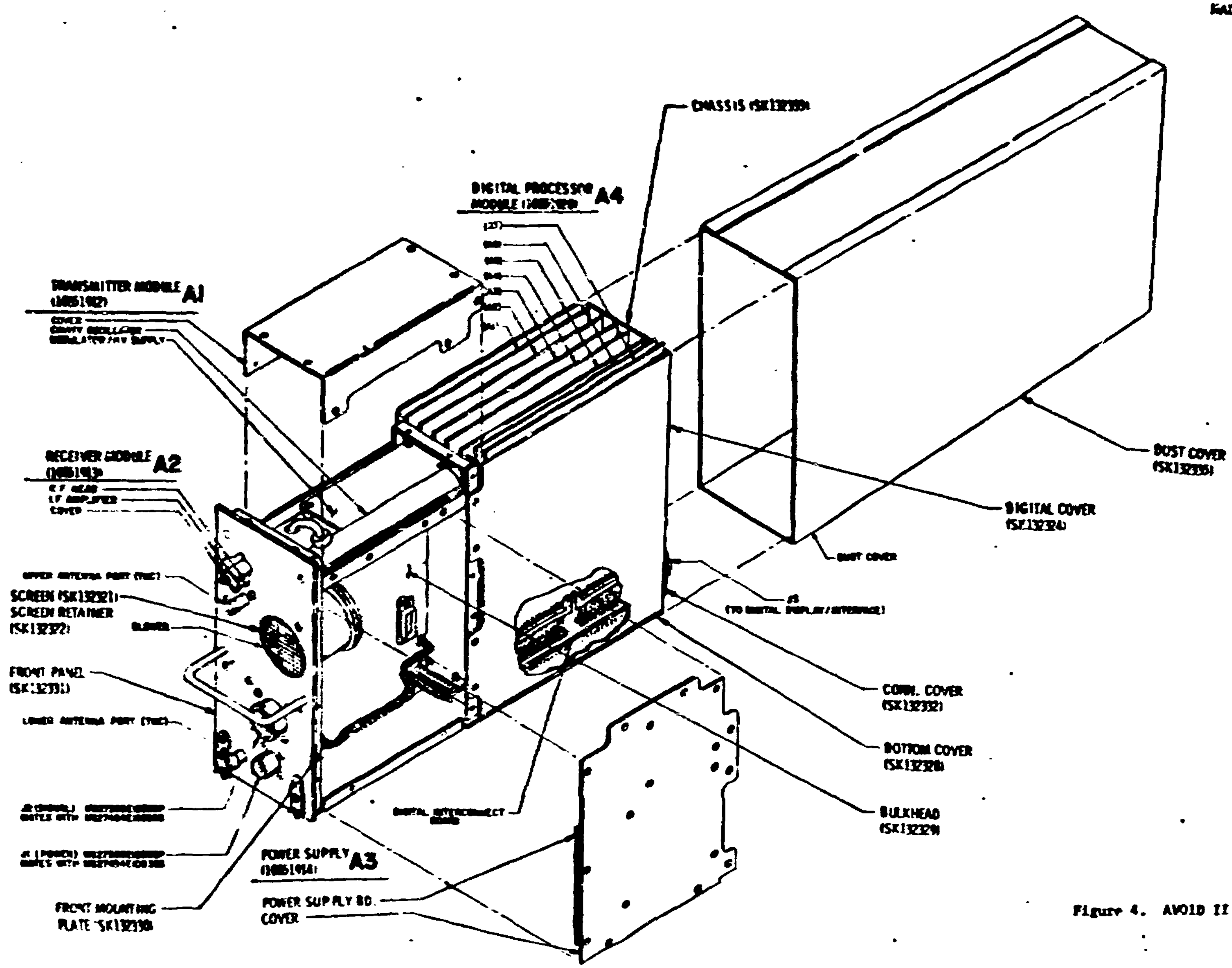


Figure 4. AVOID II with Cover Removed.

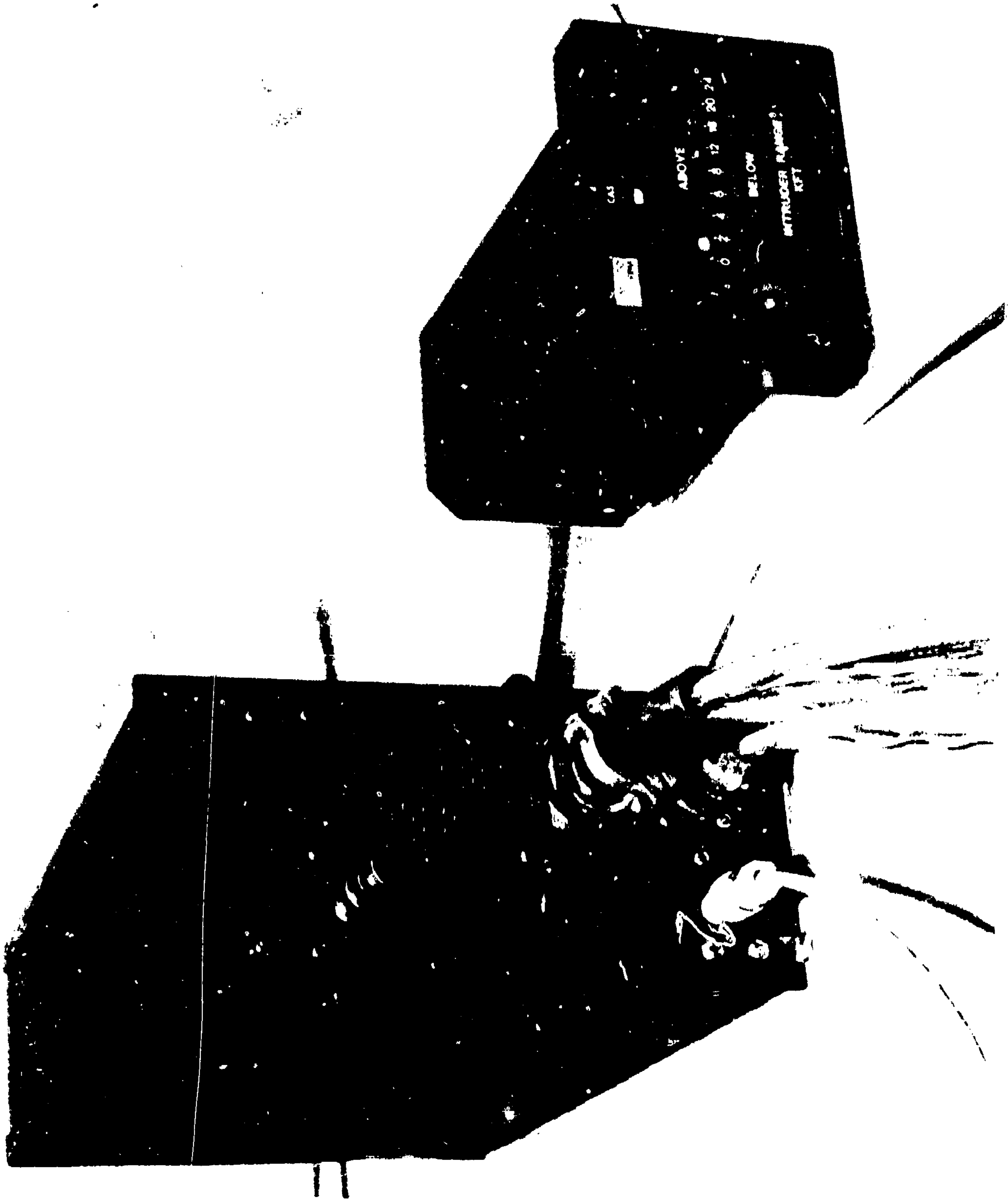


Figure 5. MOID II with Maneuver Indicator.

AVOID CAS MODIFICATIONS (PRE-AVOID II DELIVERY)

As a result of the flight test evaluation of the AVOID I by NAVAIRDEVCEN personnel, several AVOID system design changes were recommended. The following recommendations were incorporated in the AVOID II CAS equipment:

1. TAU TWO and TAU ONE threats be identified by range before being processed through the display logic to preclude the display of a threat resulting from two fruit tracks (false alarm) or one fruit track followed by a legitimate track (early alarm).

2. The two interrogation sets in the branch altitude bands be increased to five or more. This is to reduce to an acceptable level the probability of fruit falling within the altitude range acceptance gate causing an alteration of an advisory or command.

3. Fifty-foot range bins be implemented for the entire range of the CAS to reduce the formation of fruit tracks and fruit correlation in branch altitude bands.

4. The altitude code scaling factor be changed from 1 to 2 nanoseconds/foot in order to establish accurate altitude threat zone boundaries.

5. The interrogation multipath altitude response guard gate be increased from 5 microseconds to 10 microseconds.

6. Additional sets of interrogations be incorporated in the interrogation sequence to prevent formation of phantom intruder tracks which cause false alarms.

As a result of these changes to the AVOID CAS, several modifications to the previously delivered AVOID I equipments were required. The AVOID I CAS, Traffic Simulator, and Digital Display and Interface (shown in figure 6) were modified to be compatible with the AVOID II CAS. The following modifications were performed:

1. AVOID I CAS

a. Double the altitude scale factor from 1 to 2 ns/foot

b. Change the altitude band width and the relative center position to provide the necessary altitude boundaries.

c. Reduce the interrogation jitter to the level of the AVOID II CAS equipment.

d. Double the multipath guard gate (5 to 10 microseconds).

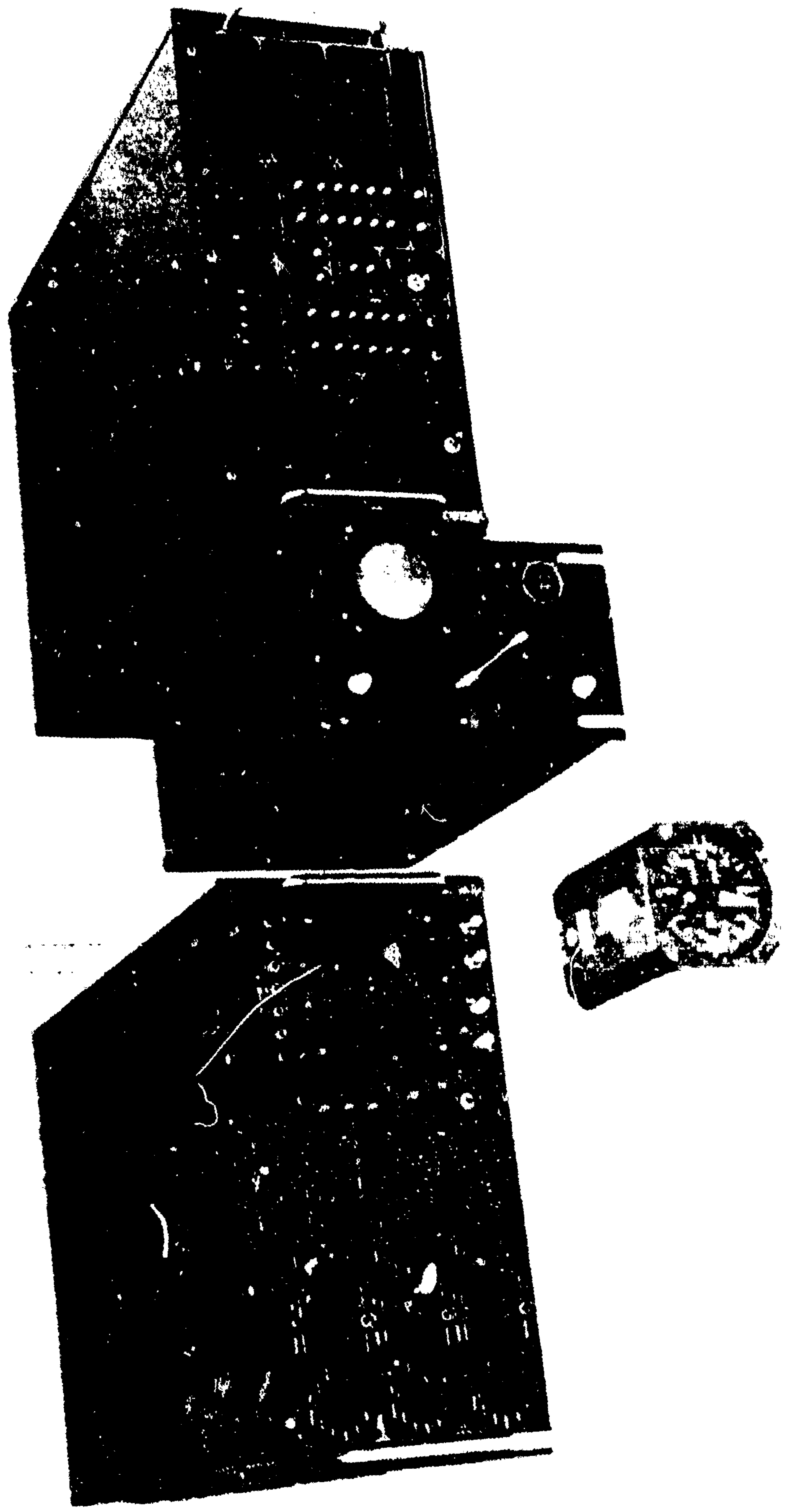


Figure [illegible]. Mode 1, ADIS traffic simulator, and pictorial display and interface.

2. Traffic Simulator

a. Double the altitude scale factor.

b. Change the circuitry which determines the position of multiple targets so that the trailing targets are in the correct position.

3. Digital Display and Interface

a. Change circuitry to allow for automatic compensation for the differences between the AVOID I and AVOID II.

b. Change the fruit and interrogation rate counting circuitry so that it is independent of AVOID I and AVOID II event duration.

c. Change the tape recorder control to enable recording of flight parameters at the end of each interrogation sequence.

AVOID CAS MODIFICATION AFTER DELIVERY

During the AVOID II flight tests, occasional phantom target tracks occurred at certain geographic locations while enroute to and returning from the Dover, Delaware VORTAC site. These phantom targets occurred without the presence of a cooperating target aircraft. After analysis of computer print-outs of the data recorded during these occurrences, it was discovered that the phantom targets occurred only at low altitudes (approximately 4000 feet), and within certain distances from buildings and large metallic objects. The recording of TACAN range and bearing data allowed accurate positioning of the aircraft at the times when the phantom target tracks occurred. It was concluded that the phantom targets were actually reflections of the aircraft's own interrogation pulses.

The original AVOID system design employed a 32.6-microsecond delay between the second interrogation pulse pair and the opening of the range acceptance window at the interrogator end of the link. The same delay occurred aboard the responding aircraft after the second interrogation pulse pair prior to the generation of a reply. This delay was intended to prevent multipath interrogations from adversely affecting various phases of system operation. The 32.6-microsecond delay prevented interrogation reflections, from objects less than 16,300 feet (4.97 kilometres) away, from entering the range gate.

In order to prevent the tracking of reflections in both the AVOID I and the AVOID II, and to maintain compatibility between the two, the 32.6-microsecond delay was increased by 229 microseconds. The new 261.6-microsecond delay protects the system from ground reflections from objects up to 21.5 miles (39.8 kilometres) away.

A successful flight test of the modification occurred on September 5, 1975. The test site was the Yardley VORTAC in Pennsylvania. This site was chosen since earlier flights in the vicinity of Yardley had resulted in phantom target tracks. A radial of the VORTAC was chosen which corresponded closely to earlier flight paths. The same course was flown six times during the test. Three of

the runs were performed with the 261.6-microsecond delay, and three with the 32.6-microsecond delay. The phantom tracks did not occur with the extended delay; however, during each run with the shorter (32.6-microsecond) delay, the phantom tracks occurred persistently. Extended flights on later dates confirmed that the modification was effective since no phantom tracks occurred in regions where they had previously.

AIRCRAFT INSTALLATION AND FLIGHT TEST INSTRUMENTATION

AIRCRAFT INSTALLATION

The three NAVAIRDEVCEN aircraft provided for this flight test evaluation were the NC-117 (BuNo 12431), the P-3A (BuNo 148883), and the RA-3B (BuNo 144833). The maximum airspeed capabilities were as follows:

NC-117 - 160 knots (82 m/s)

P-3A - 300 knots (154 m/s)

RA-3B - 550 knots (283 m/s)

The performance characteristics of these aircraft exceeded the limits for which the AVOID II CAS was designed. As a consequence, the following instructions for maneuvers in response to the pilot display indicator were followed in order to duplicate the performance of general aviation aircraft:

1. 1/4 g maneuver (2.5 m/s^2)

2. Hold up to maximum of 1000 fpm until command is extinguished

3. Level off with 1/4 g maneuver

The RA-3B did not follow these restrictions since it was equipped with an AVOID I. Comparable maneuver values were 1/4 g and 2000 fpm.

The NC-117 and P-3A installations consisted of the following equipments:

1. AVOID II CAS

2. AVOID II Maneuver Indicator (in cockpit), CAS/VSI indicator at project installation location.

3. Digital display and interface

4. Traffic simulator

5. Kennedy Model 1708 Digital Tape Recorder

6. Time synchronization system

   a. General Radio 1115-C standard frequency oscillator

b. General Radio 1123-A digital synchronometer

c. General Radio 1124 WWV receiver and oscilloscope

7. AN/ARN-84 airborne TACAN set

8. Intercontinental Dynamics Corporation Type 518-16007-V212 digitizing barometric altimeter

The RA-3B had the same instrumentation but was equipped with an AVOID I CAS. The antenna locations and cable lengths are listed in table I. Outline drawings of each aircraft, showing locations of the upper and lower CAS antenna, are provided in figures 7, 8, and 9.

DATA ACQUISITION

The principal source of data was the digital incremental tape recorder in conjunction with the digital interface. The digital interface accumulated the following information supplied by the AVOID II:

- Target range
- Target range rate
- TAU
- Number of interrogations transmitted
- Number of interrogations received
- Number of replies received (including fruit replies)
- Threat levels including intermediate display logic levels

In addition, the digital interface acquired the relevant reference parameters (see figure 10) including precise time, digitized barometric altitude, and TACAN range and bearing at the end of each evaluation sequence. The digital interface multiplexes the accumulated data into the buffer of the incremental tape recorder and provides the write data strobe which enables the recorder to transfer the data onto tape. The data format is shown in figure 11. The on-board digital clock system provided the exact time of each AVOID II processing and display sequence. The precision clocks were synchronized prior to takeoff to within a few milliseconds. Consequently, data gathered in different aircraft could be compared and analyzed. The installation interconnect diagram is shown in figure 12.

At the conclusion of each flight, the data tapes generated on each aircraft were processed on the NAVAIRDEVCEN CDC 6600 computer system. The computer software necessary for decoding, reducing and analyzing data tapes was developed by NAVAIRDEVCEN engineers. Sample print-outs are shown in figures 13 and 14, with the nomenclature explained in table II.

TABLE I. ANTENNA LOCATIONS

	Lower Antenna			Upper Antenna		
Aircraft	Station inches	Centerline Offset inches	Lead-in lengths feet	Station inches	Centerline Offset inches	Lead-in lengths feet
RA3B	175	19 port	13	283	0	3
NC117	22	0	50	51	0	40
P3A	383	10 port	21	350	0	11

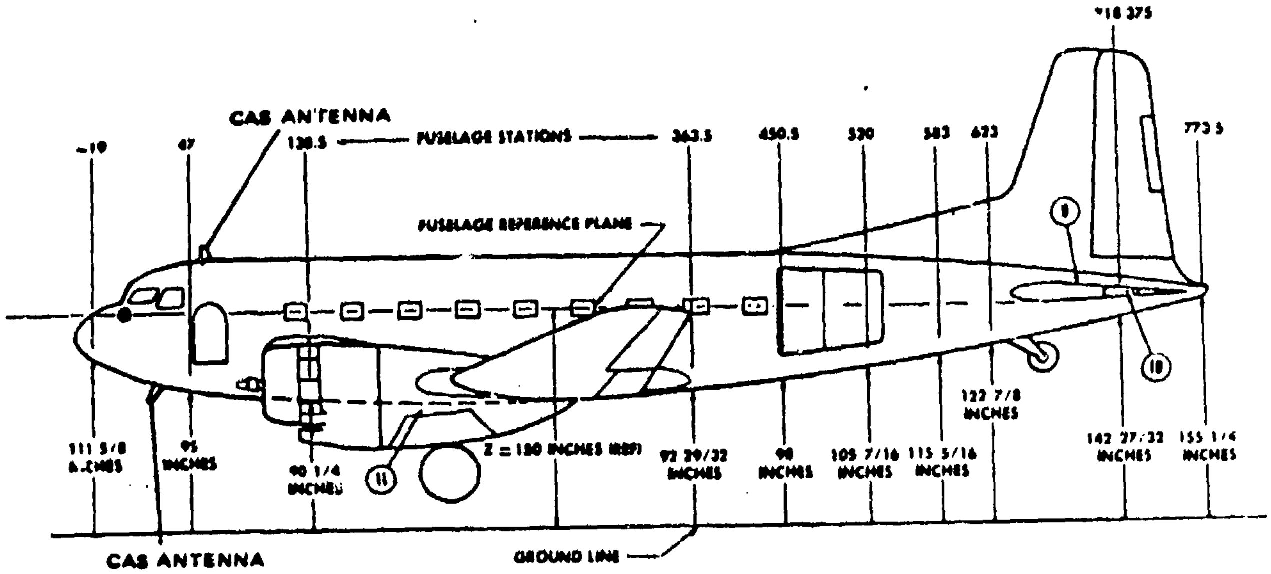


Figure 7. CAS Antenna Locations - NC-117.

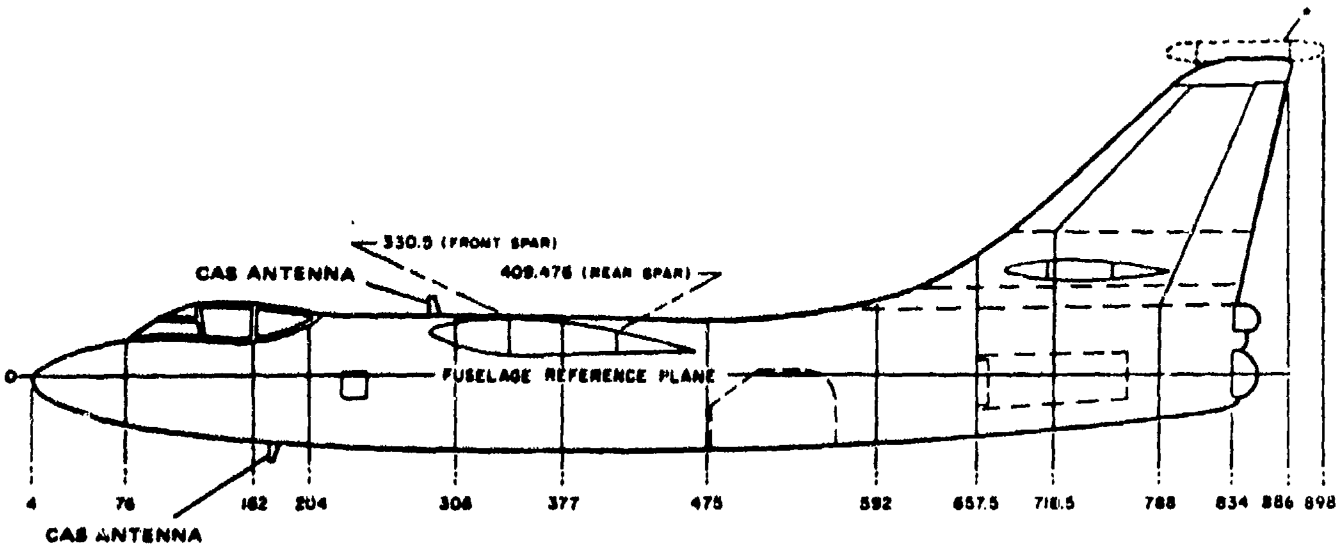


Figure 8. CAS Antenna Locations - RA-3B.

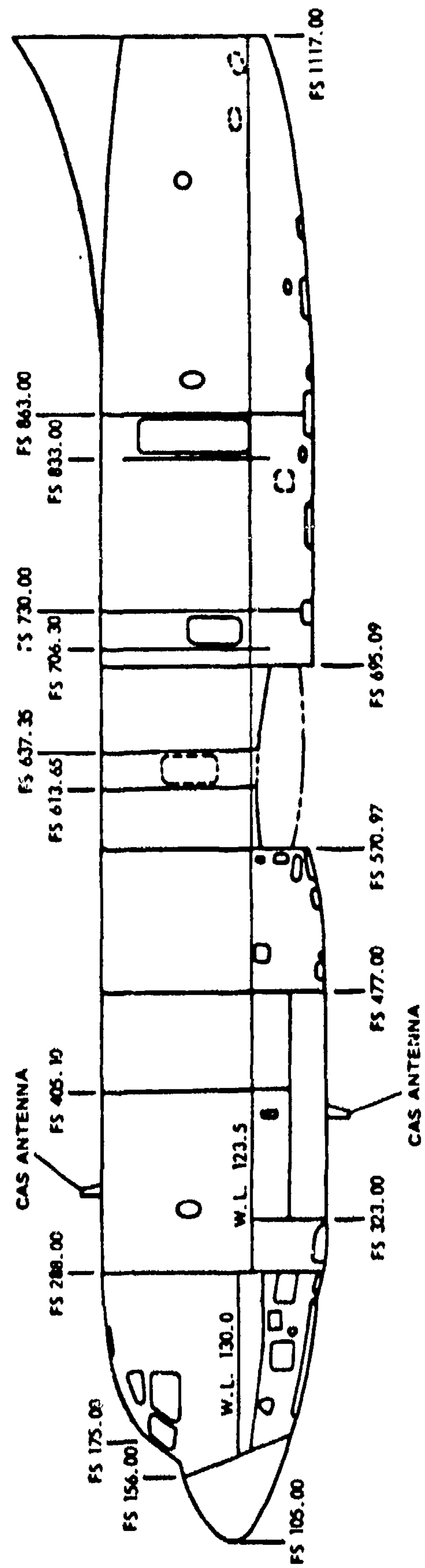


Figure 9. CAS Antenna Locations - P-3A.

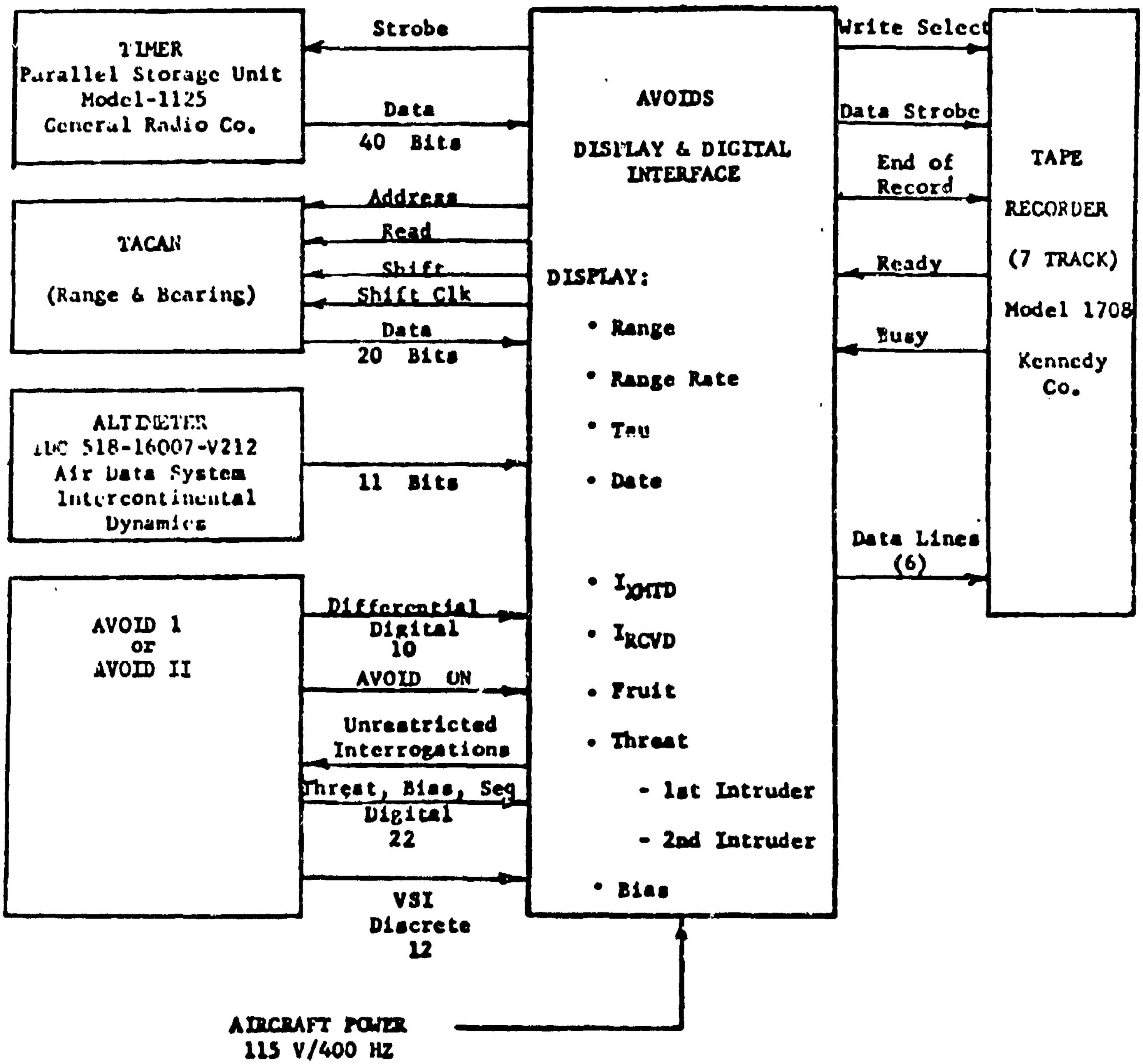
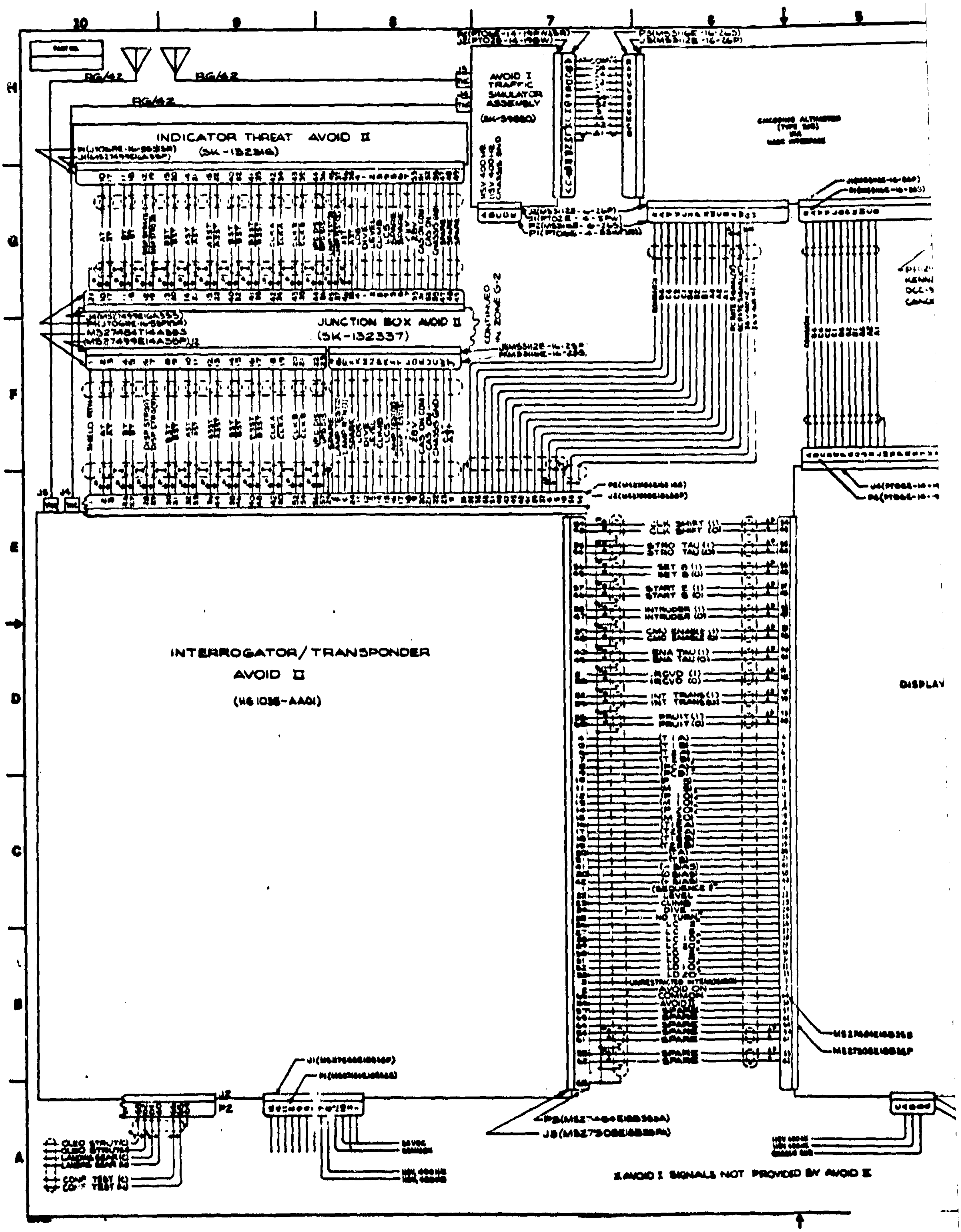


Figure 10. Digital Interface Data Transfer.

Function			MUX IC #	CHAR	MUX PIN #	Track B	Track A	MUX ASSY 6 A4: 8	A3: 4	A2: 2	A1: 1	Octave	Code	Comment
DATE	MO	Tens	8-6	1	30			X	X	X	X	1	BCD	All data provided on 4 tracks 8, 4, 2, 1
		Units		2	5			X	X	X	X			
	DAY	Tens		3	29			X	X	X	X			
		Units		4	4			X	X	X	X			
FLT NO		Tens		5	3			X	X	X	X			
		Units		6	28			X	X	X	X			Parity provided on track B
TIME	HR	Tens		7	61			X	X	X	X	***		
		Units		8	23			X	X	X	X	TP 35		
	MIN	Tens	7-44	9	93			X	X	X	X	2		
		Units		10	68			X	X	X	X			
	SEC	Tens		11	67			X	X	X	X			
		Units		12	66	PARITY		X	X	X	X			Track A interface provided as a logic "0" always
		Tenths		13	69			X	X	X	X			
		Hundredths		14	70			X	X	X	X			
		Thousandths		15	65			X	X	X	X	***		
		Ten Thousandths		16	62			X	X	X	X	TP 37		
1ST INTRUDER	RANGE FT	Hundred Thousands	8-14	17	11			X	X	X	X	3		
		Ten Thousands		18	10			X	X	X	X			
		Thousands		19	9			X	X	X	X			
		Hundreds		20	8			X	X	X	X		BCD	
	RATE FT/SEC	Sign Bit		21	34			X			X		Binary	← Char 21
		Thousands		22	35			X	X	X	X		BCD	Bit 8 Display Bit "1" Display 1 "0" Display 2
		Hundreds		23	36			X	X	X	X	***		
		Tens		24	37			X	X	X	X	TP 39		
	TAU SEC	Tens	8-22	25	20			X	X	X	X	4		Bit 1 Sign Bit "1" Positive "0" Negative
		Units		26	19			X	X	X	X			
2ND INTRUDER	RANGE FT	Hundred Thousands		27	17			X	X	X	X			
		Ten Thousands		28	41			X	X	X	X			
		Thousands		29	42			X	X	X	X			Same for Char 31
		Hundreds		30	43			X	X	X	X		BCD	
	RATE FT/SEC	Sign Bit		31	44						X	***	Binary	
		Thousands		32	45			X	X	X	X	TP 41	BCD	
		Hundreds	8-30	33	79			X	X	X	X	5		
		Tens		34	54			X	X	X	X			
	TAU SEC	Tens		35	53			X	X	X	X			
		Units		36	52			X	X	X	X			
[illegible]	RCVR	Ten Thousands		37	51	PARITY		X	X	X	X			
		Thousands		38	76			X	X	X	X	***		
		Hundreds		39	77			X	X	X	X	TP 47		
[illegible]	[illegible]	Ten		40	78			X	X	X	X			
		Units	8-38	41	58			X	X	X	X	6		
[illegible]	RCVR	Thousands		42	82			X	X	X	X			
		Hundreds		43	56			X	X	X	X			
		Tens		44	81			X	X	X	X			
		Units		45	80			X	X	X	X		BCD	
VTI				46	48			X	X	X	X	***	Binary	
				47	49			X	X	X	X	TP 53		
				48	24			X	X	X	X			
TACAN RANGE			7-14	49	** Via 40			X	X	X	X	7	Binary	
				50				X	X	X	X			
				51				X	X	X	X			
				52				X	X	X	X			
				53				X	X	X	X			
[illegible]	1			54	12			X	X	X	X	***		
				55	38			X	X	X	X	TP 55		
				56	13			X	X	X	X			
[illegible]	2		7-22	57	21			X	X	X	X	8		
				58	46			X	X	X	X			
				59	18			X	X	X	X			
BIAS/SEQ				60	16			X	X	X	X			← Char 60
TACAN BEARING				61	** Via 40			X	X	X	X			Bit 8 Bias +
				62				X	X	X	X			Bit 4 Bias 0
				63				X	X	X	X	***		Bit 2 Bias -
				64		PARITY		X	X	X	X	TP 51	Binary	Bit 1 Sequence Bit "1" SEQ 1 "0" SEQ 2
ALT			7-38	65				X	X	X	X	9	Gry Code	
				66	96			X	X	X	X		Gry Code	
				67	97			X	X	X	X		Gry Code	
				68	98			X	X	X	NC			
[illegible]	NO	Tens		69	57			X	X	X	X			
		Units		70	83			X	X	X	X			
ALL THREATS				71	84			X	X	X	X	***		
				72	52			X	X	X	X	TP 49		
			8-46	73	63			X	X	X	X	10		← Char 73
				74	64			X	X	X	X			Bit 2 Intruder 1 VE
				75	88			X	X	X	X			Bit 1 Intruder 2 VE
				76	87			X	X	X	X			
SPARE				77	89									
				78	90							***		
				79	91							TP 45		
				80								TRIGGER		

** TACAN DATA MULTIPLEXED
*** TRIGGER IS TEST POINT ON PROGRAMMER FOR THE PREVIOUS OCTAVE

Figure 11. Digital Interface Data Format


INDICATOR THREAT AVOID II
JUNCTION BOX AVOID II
(SK-132337)
INTERROGATOR/TRANSPONDER
AVOID II
AVOID I TRAFFIC SIMULATOR ASSEMBLY
RG/42
DISPLAY
CONTINUED IN ZONE G-2
SPARE
*AVOID I SIGNALS NOT PROVIDED BY AVOID II

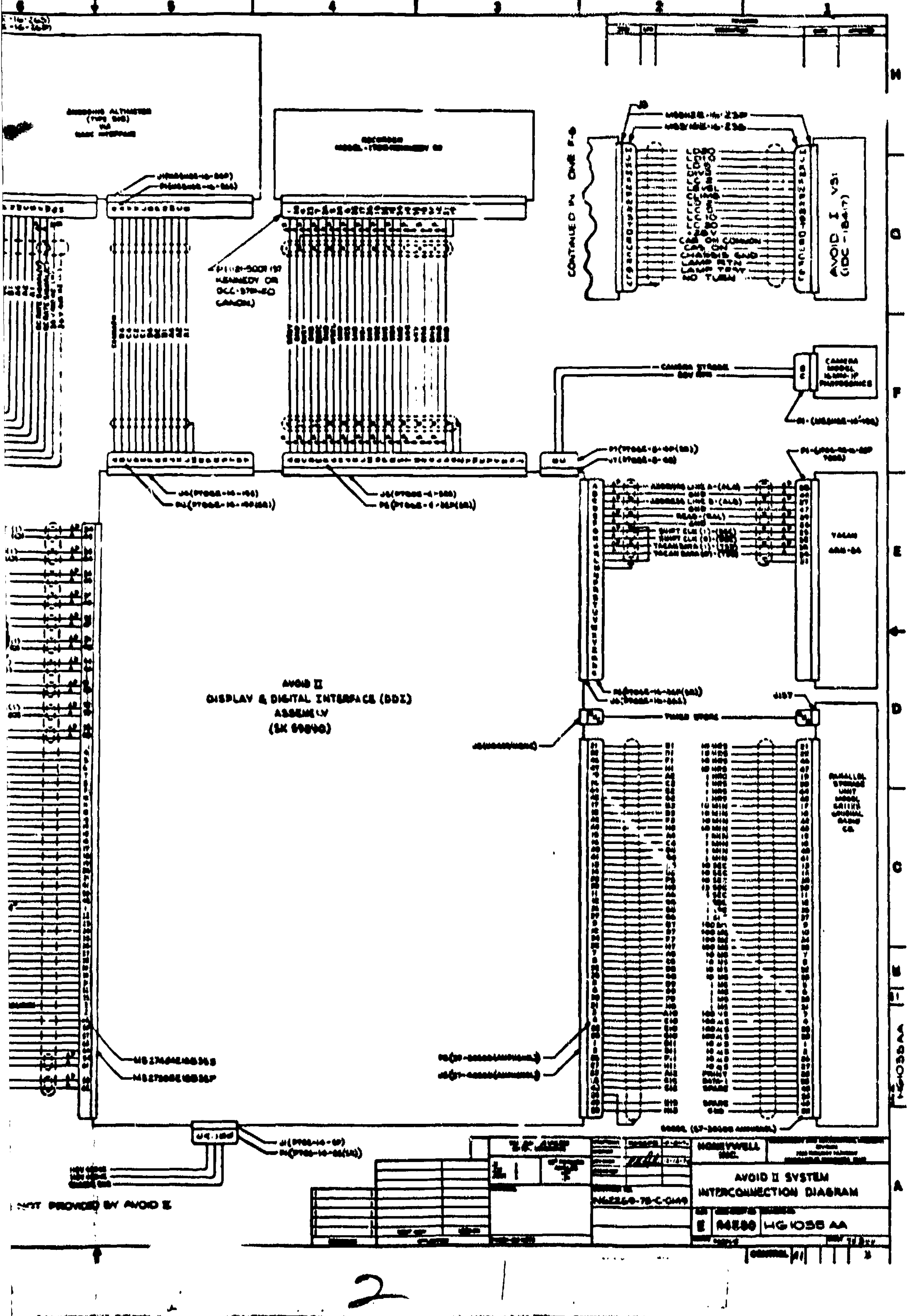


Figure 12. Installation Interconnect Diagram.

FLIGHT NO. 4 ENCOUNTER NO. 24 DATE 7 2

TIME HR	MIN	SEC	DISPLAY	TARGET NO. 1 RANGE	RATE	TAU	THR 1	TARGET NO. 2 RANGE	RATE	TAU	THR 2	ALT	RPLS	XMT	FREQ		
14	29	11.7		.000	0	0		.000	0	0		9.8	39.7	3	1722		
14	29	15.3		.000	0	0		.000	0	0		9.8	39.6	3	1730		
14	29	19.0		.000	0	0		.000	0	0		9.8	39.1	0	1701		
14	29	22.7		.000	0	0		.000	0	0		9.8	39.6	3	1724		
14	29	26.5		.000	0	0		.000	0	0		9.8	39.6	3	1743		
14	29	30.3		.000	0	0		.000	0	0		9.8	39.4	3	1688		
14	29	34.3		.000	0	0		.000	0	0		9.8	39.3	3	1677		
14	29	37.7		.000	0	0		.000	0	-0		9.8	39.4	3	1721		
14	29	41.5		.000	0	0		.000	0	0		9.8	39.8	3	1754		
14	29	45.2		3.835	379	30	CA2	.000	0	0		9.8	39.3	14	1722	T2A -	
14	29	45.8	500A	3.473	357	34	CA2	.000	0	0		9.8	39.9	17	1753	T2A	
14	29	52.7	500A	3.378	373	29	CA1	.000	0	0		9.8	39.3	16	1658		T1A
14	29	55.3	DIVE	2.715	373	26	CA1	.000	0	0		9.8	39.7	16	1785		T1A
14	30	.1	DIVE	2.337	367	22	CA1	.000	C	0		9.8	39.3	16	1733		T1A
14	30	3.3	DIVE	1.958	379	18	CA1	.000	0	0		9.8	39.7	17	1711		T1A
14	30	7.5	DIVE	1.580	373	15	CA1	.000	0	0		9.7	39.7	16	1741		T1A
14	30	11.3	DIVE	1.231	373	11	CA1	.000	0	0		9.7	39.4	16	1714		T1A
14	30	15.1	DIVE	.923	367	8	13A	.000	C	0		9.6	39.6	17	1742	P5	
14	30	18.7	500A	.477	353	4	13A	.000	0	0		9.5	39.7	13	1733	P5	
14	30	22.5	500A	.000	0	0		.000	0	0		9.5	39.5	12	1733		
14	30	26.2		.000	0	0		.000	0	0		9.5	39.4	11	1722		
14	30	23.3		.000	C	0		.000	C	0		9.5	39.4	3	1582		
14	30	33.6		.000	C	0		.000	0	0		9.5	39.7	4	1715		
14	30	[illegible]		.000	C	C		.000	C	0		9.6	39.5	3	1635		
14	30	41.1		.000	0	0		.000	0	0		9.7	40.0	3	1748		
14	30	45.0		.000	0	0		.000	0	0		9.7	39.8	3	1723		
14	30	48.7		.000	0	0		.000	0	0		9.8	39.7	3	1738		
14	30	52.4		.000	0	0		.000	0	0		9.8	39.8	3	1715		
14	30	56.2		.000	0	0		.000	0	0		9.8	39.6	3	1704		
14	31	.0		.000	0	0		.000	0	0		9.8	39.5	3	1698		
14	31	3.9		.000	0	C		.000	0	0		9.8	39.4	3	1731		
14	31	7.5		.000	0	C		.000	0	0		9.8	39.5	3	1740		
14	31	11.2		.000	0	0		.000	0	0		9.8	39.5	2	1717		
14	31	15.0		.000	0	0		.000	0	0		9.7	39.7	3	1725		
14	31	18.8		.000	0	0		.000	0	0		9.7	39.2	3	1659		
14	31	22.5		.000	0	0		.000	0	0		9.7	39.6	3	1746		
14	31	26.3		.000	0	C		.000	0	0		9.7	39.6	3	1742		
14	31	30.3		.000	0	C		.000	C	0		9.7	39.4	3	1797		
14	31	33.7		.000	0	C		.000	C	0		9.7	39.3	3	1719		
14	31	37.5		.000	0	0		.000	0	0		9.7	39.7	3	1740		
14	31	41.2		.000	C	0		.000	0	0		9.7	39.4	3	1726		
14	31	44.9		.000	0	C		.000	C	0		9.7	39.5	3	1740		
14	31	48.7		.000	0	0		.000	0	0		9.7	39.6	3	1737		
14	31	52.4		.000	0	C		.000	C	0		9.7	39.3	3	1723		
14	31	56.0		.000	0	0		.000	C	0		9.7	39.6	3	1723		

Figure 13. Computer Printout of Data (I).

TIME HR	MIN	SEC	DISPLAY	TARGET NO. 1 RANGE	RATE	TACAN RANGE	BEARING
14	28	7.8		.000	0	5.900	258.00
14	28	11.6		.000	0	5.750	258.50
14	28	15.3		.000	0	5.600	258.00
14	28	19.0		.000	0	5.475	258.50
14	28	22.7		.000	0	5.300	259.00
14	28	25.5		.000	0	5.225	257.25
14	28	30.2		.000	0	5.000	254.00
14	28	33.9		.000	0	4.875	254.50
14	28	37.7		.000	0	4.775	255.50
14	28	41.4		.000	0	4.650	256.50
14	28	45.2		.000	0	4.525	255.25
14	28	49.0		.000	0	4.400	255.25
14	28	52.8		.000	0	4.225	257.25
14	28	56.4		.000	0	4.075	250.25
14	29	.3		.000	0	3.925	253.00
14	29	4.1		.000	0	3.850	252.25
14	29	7.9		.000	0	3.625	253.25
14	29	11.7		.000	0	3.475	248.00
14	29	15.3		.000	0	3.375	258.50
14	29	19.0		.000	0	3.275	257.75
14	29	22.7		.000	0	3.050	248.00
14	29	26.5		.000	0	2.400	258.00
14	29	30.3		.000	0	1.775	253.75
14	29	34.0		.000	0	1.150	232.25
14	29	37.7		.000	0	2.550	253.75
14	29	41.5		.000	0	2.475	241.25
14	29	45.2		3.835	379	2.375	249.25
14	29	48.9	500A	3.473	367	2.300	241.00
14	29	52.7	500A	3.078	373	2.175	245.00
14	29	56.3	DIVE	2.716	373	2.050	254.75
14	30	.1	DIVE	2.337	367	2.025	259.25
14	30	3.8	DIVE	1.958	379	1.900	252.25
14	30	7.6	DIVE	1.580	373	1.850	290.25
14	30	11.3	DIVE	1.201	373	1.825	274.00
14	30	15.1	DIVE	.823	367	1.450	199.75
14	30	18.7	500A	.477	355	1.550	209.50
14	30	22.5	500A	.000	0	1.325	341.00
14	30	26.2		.000	0	1.125	287.00
14	30	29.9		.000	0	1.700	56.00
14	30	33.6		.000	0	1.825	75.50
14	30	37.4		.000	0	1.975	82.25
14	30	41.1		.000	0	1.950	75.75
14	30	45.0		.000	0	2.100	68.50
14	30	48.7		.000	0	2.175	63.75
14	30	52.4		.000	0	2.275	70.25
14	30	56.2		.000	0	2.375	70.25
14	31	.0		.000	0	2.400	81.00
14	31	3.9		.000	0	2.525	83.25
14	31	7.5		.000	0	2.675	91.00
14	31	11.2		.000	0	2.825	70.75
14	31	15.0		.000	0	2.975	77.00
14	31	18.8		.000	0	3.075	73.75
14	31	22.5		.000	0	3.175	74.25
14	31	26.3		.000	0	3.350	72.75
14	31	30.0		.000	0	3.475	74.75
14	31	33.7		.000	0	3.550	73.00
14	31	37.5		.000	0	3.725	75.50
14	31	41.2		.000	0	3.875	74.75
14	31	44.9		.000	0	3.975	73.75
14	31	48.7		.000	0	4.075	76.75
14	31	52.4		.000	0	4.225	74.25
14	31	56.0		.000	0	4.250	73.25
14	31	59.9		.000	0	4.575	73.00
14	32	3.7		.000	0	4.725	75.25

Figure 14. Computer Printout of Data (II).

TABLE II. COMPUTER PRINTOUT GLOSSARY

Display - A print-out of what the pilot sees displayed on his CAS indicator

Target No. 1 - That target which is closest in range in the first altitude band interrogated containing targets

Target No. 2 - That target which is closest in range in the next altitude band containing a target

Range - The slant range between own aircraft and intruder aircraft in thousands of feet (Section 1); nmi (Section 2)

Rate - The first derivative of slant range with respect to time in feet per second (Section 1); knots (Section 2)

TAU - The range divided by the range rate - the time to collision if two aircraft are on a collision course in seconds

THR 1 - The threat status of target No. 1 inputed to the threat logic matrix the output of which is displayed on the CAS/VSI indicator

Examples:

CB1 - coaltitude below TAU 1
CB2 - coaltitude below TAU 2
CA1 - coaltitude above TAU 1
13A - $\leq$1300 feet above
13B - $\leq$1300 feet below

THR 2 - The threat status of target No. 2 inputed to the threat logic matrix

ALT - Own altitude derived from digitizing barometric altimeter-thousands of feet

RPLS - The sum of real, and simulated target replies from the traffic simulator injected into the front end of the AVOID receiver (representing aircraft replies (fruit) to interrogations other than those from own aircraft) in hundreds of pulses per second

I XMT - The number of times the AVOID CAS interrogates the aircraft population - pulse quads per second

I RCD - The number of interrogations received by the AVOID from the aircraft population.

ALL THREATS - Since the digital display and interface contains only two tracking channels, it is desirable to have the capability of displaying the

TABLE II. COMPUTER PRINTOUT GLOSSARY (continued)

threat status of additional targets; this is accomplished in the print-out of the ALL Threats Data (intermediate display logic)

BIAS - To ensure complementary vertical maneuvers in a TAU 1 situation, when the altitude separation is measured as $\leq$400 feet, the responding aircraft, which has assessed the threat, biases the altitude with which he responds by 200 feet in the direction of the escape maneuver

Examples:

(+) own altitude biased +200 feet
(-) own altitude biased -200 feet

TACAN Range - Range in nautical miles to TACAN beacon (air-to-ground mode); range nmi between aircraft (air-to-air mode) to nearest thousandth of a mile

TACAN Bearing - Bearing in degrees of the TACAN radial being flown to nearest hundredth of a degree (air-to-ground mode); bearing to another aircraft (air-to-air) not available yet

FLIGHT TEST PLAN SUMMARY

INTRODUCTION

A NAVAIRDEVCEN flight plan[3] contains the details of the AVOID II flight test plan. The primary objectives of these flight tests were to:

1. Determine the communication reliability as well as the pilot's display reliability as a function of range and aircraft encounter angle.

2. Determine the range, range rate, and warning time accuracies.

3. Determine the effectiveness of the AVOID II operation in the presence of the simulated air traffic fruit environment representative of the 1970-1990 era.

4. Determine the effectiveness of the protected volume provided by the AVOID II.

5. Verify the compatibility of the AVOID II with the AVOID I in regard to communication reliability, proper threat determination, and the generation of the necessary warning times.

GENERAL OPERATION TESTS

The head-on and tail chase encounters were used to develop repetitive data in order to obtain the effective communication range as a function of communication reliability. In addition, they supplied data which determined the warning times provided by the AVOID II at various closing range rates as well as the alarm display consistency.

The AVOID II transmits pulses at a level in excess of 54 dbm, and operates with a receiver sensitivity which is better than -68 dbm. The communication loop sensitivity between equipments is therefore greater than 122 dbm. This level represents an average communication range of 8.4 nmi.

The tracking range of the AVOID II is limited by the number of positions in the high-speed RAM (random access memory) into which interrogation responses are clocked. The current AVOID II equipment utilizes a 512 X 1 bit RAM. With each bit representing a 50 ft (15.2 m) range sector, the last range bit corresponds to a range of 25,600 ft (7.8 kilometre) or approximately 4.2 nmi. With the present threat logic, this range provides Tau-1 warning times of 25 seconds for closing rates up to 760 ft/sec (231 m/s) (450 kn). For other angles between flight paths and various aircraft velocities (250 kn (129 m/s) limit for aircraft below 10,000 ft altitude), the hazard radius is proportionately less. The AVOID II threat zones are shown in figure 15 and the associated command display logic is shown in figure 16.

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[3]NAVAIRDEVCEN Flight Test Plan for AVOID II CAS Code 6071 of March 1975.

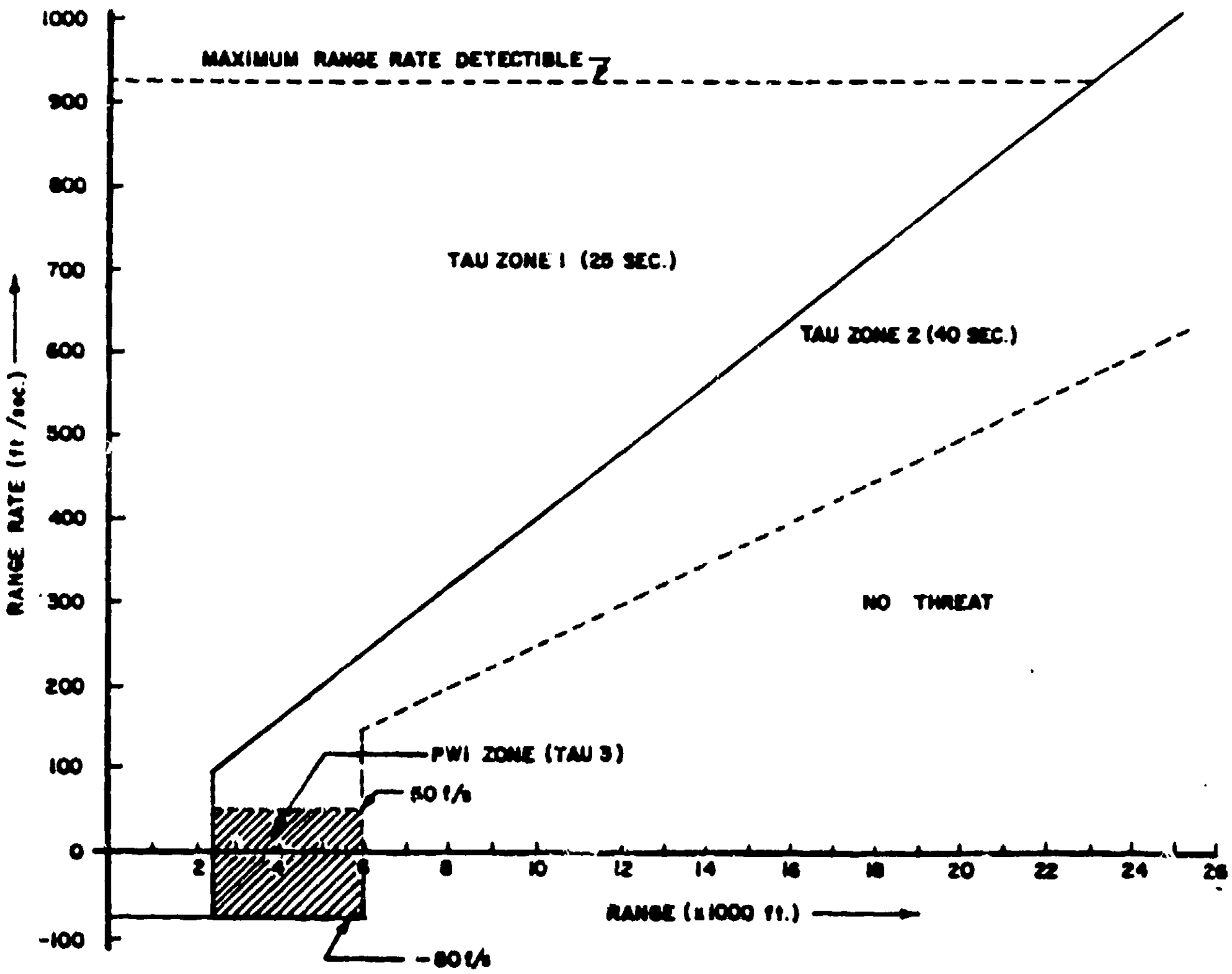


Figure 15. AVOID II Threat Zones.

INTRUDER BELOW / INTRUDER ABOVE	TAU 1 THREAT (Co-Altitude above)	TAU 1 OR TAU2 THREAT (Above band)	NO THREAT
NO THREAT	DIVE	* LVS < 500 FPM UP	NO COMMAND
TAU 1 OR TAU 2 THREAT (Below band)	DIVE LVS < 500 FPM DOWN	LVS < 500 FPM UP LVS < 500 FPM DOWN	LVS < 500 FPM DOWN
TAU 1 THREAT (Co-Altitude below)	FLY LEVEL	CLIMB LVS < 500 FPM UP	CLIMB

* LVS - Limited Vertical Speed

Figure 16. Command Display Logic.

ALTITUDE BOUNDARIES AND ALTITUDE DISCRIMINATION TESTS

The main objective of these encounters was to determine the ability of the AVOID II to define altitude bands and the reliability of the altitude discrimination in the vicinity of altitude threat zone boundaries. In particular, these encounters should verify that the equipment can distinguish relative altitude to the accuracy necessary for effective intruder threat analysis as well as provide the proper warning.

The AVOID II CAS classifies the target on the basis of the replies that the aircraft receives in response to its altitude-coded interrogations. Interrogations are sequentially biased to determine occupancy of a threat status band. This is possible because aircraft respond only to interrogations of bands which include their altitude.

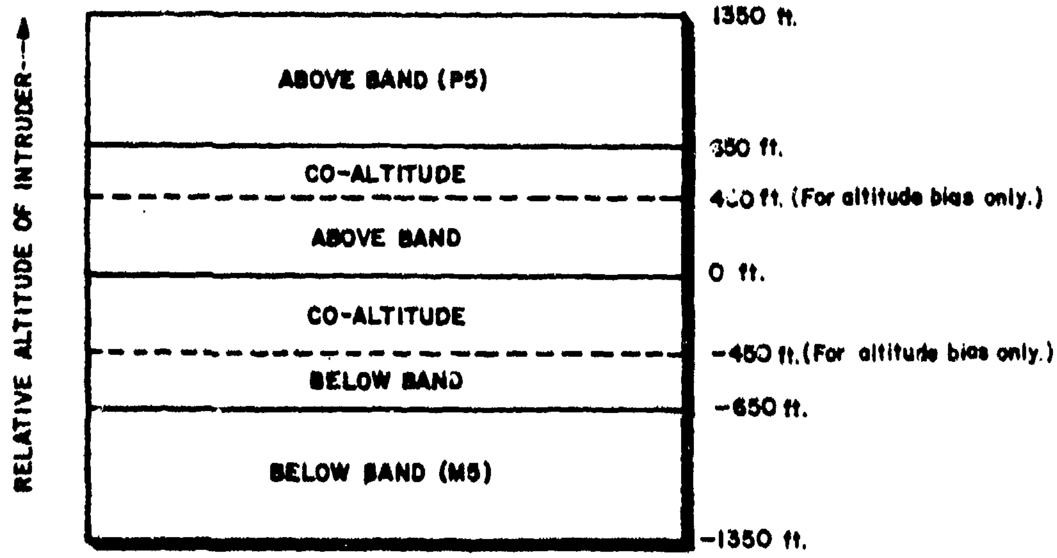
The AVOID II altitude threat zones are shown in figure 17. The AVOID II classifies threats as a result of replies to the interrogation pattern shown in figure 18. The co-altitude interrogations determine whether threatening aircraft are within ±600 ft (±183 m) relative altitude. It is necessary that the equipment be capable of distinguishing this boundary both accurately and consistently. Poor resolution of either the ±600 ft or ±400 ft (±122 m) relative altitude boundaries would result in an unstable situation in which the pilot's display would alternate between commands (DIVE or CLIMB) and advisories (LIMIT VERTICAL SPEED).

COMPATIBILITY TESTS

The objective of this type of flight was to verify the compatibility of the AVOID I and AVOID II. In particular, ascertain the ability of the equipments to communicate reliably while having different communication ranges, and verify the compatibility of the different Tau zone thresholds.

Due to the greater communication range (i.e. 58 to 62 dbm power output) of the AVOID I, the AVOID II will normally receive responses to its interrogations when an AVOID I equipped aircraft is within the tracker bin correlation range of the AVOID II (25,600 ft (7.8 km) or 4.2 nmi). Since the AVOID II transmits its replies and interrogations at a level about 4-dbm below an AVOID I unit, the communication range will consequently be less than the link between two AVOID I equipped aircraft. The compatibility flight tests will determine if the reduced communication range adversely affects the effective protected volume of an AVOID I equipped aircraft.

Since the AVOID II does not expand its relative altitude coverage when ascending or descending, the possibility of an AVOID II equipped aircraft ascending or descending into the proximity of an AVOID I equipped aircraft without sufficient warning time for one or both aircraft must also be investigated. Another aspect of compatibility between AVOID I and AVOID II is the effectiveness of their combined threat zones. It is necessary that the AVOID II threat zones result in maneuvers which do not detract from the safety margin provided by the implementation of ANTC-117 threat zones in the AVOID I. The AVOID I threat zones are shown in figure 19.



NOTE: ALTITUDES SHOWN ARE ACTUAL RELATIVE ALTITUDES, NOT DIGITAL ENCODING ALTIMETER ALTITUDES.

Figure 17. Altitude Threat Zones.

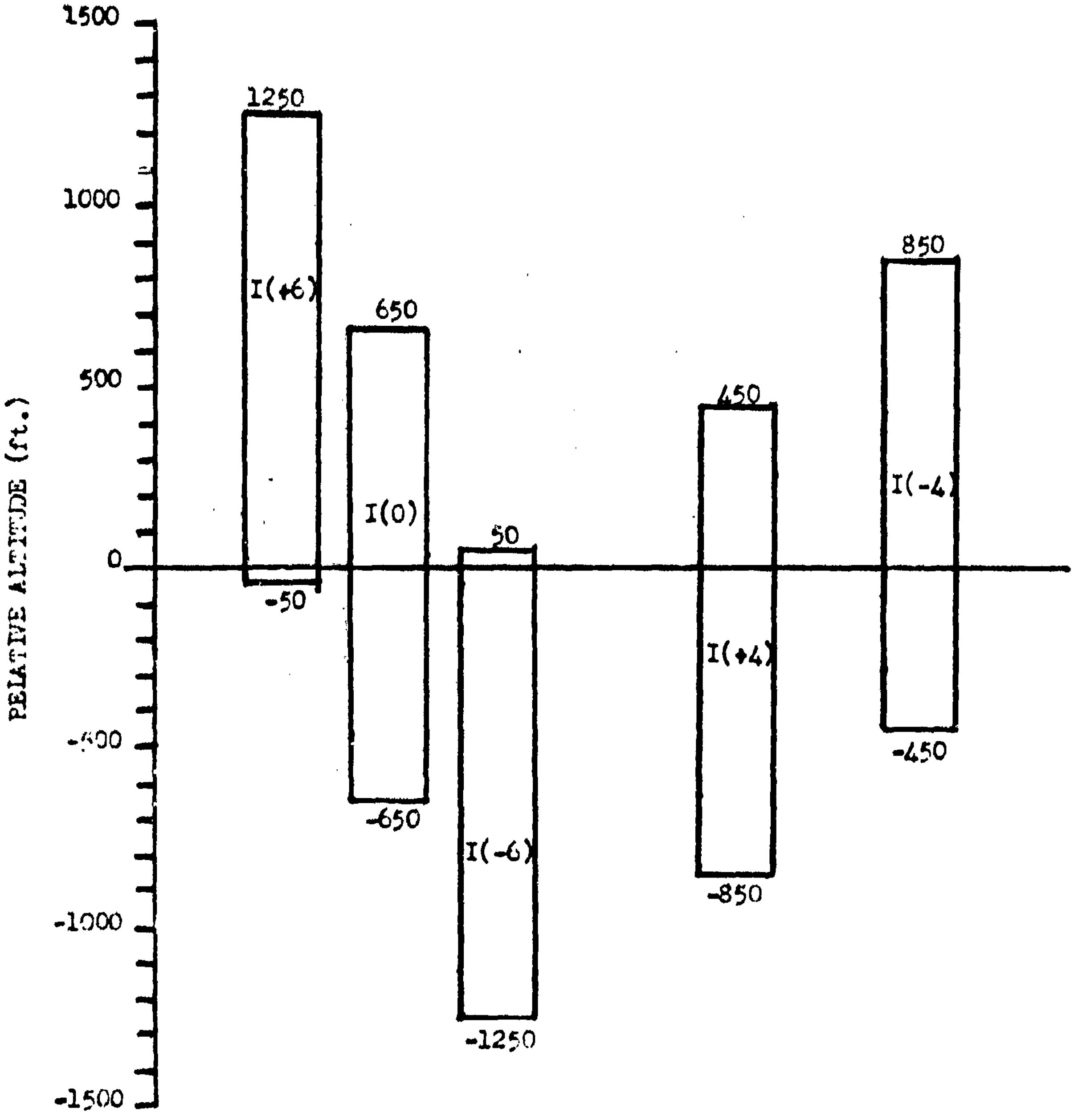


Figure 18. Interrogation Altitude Bands.

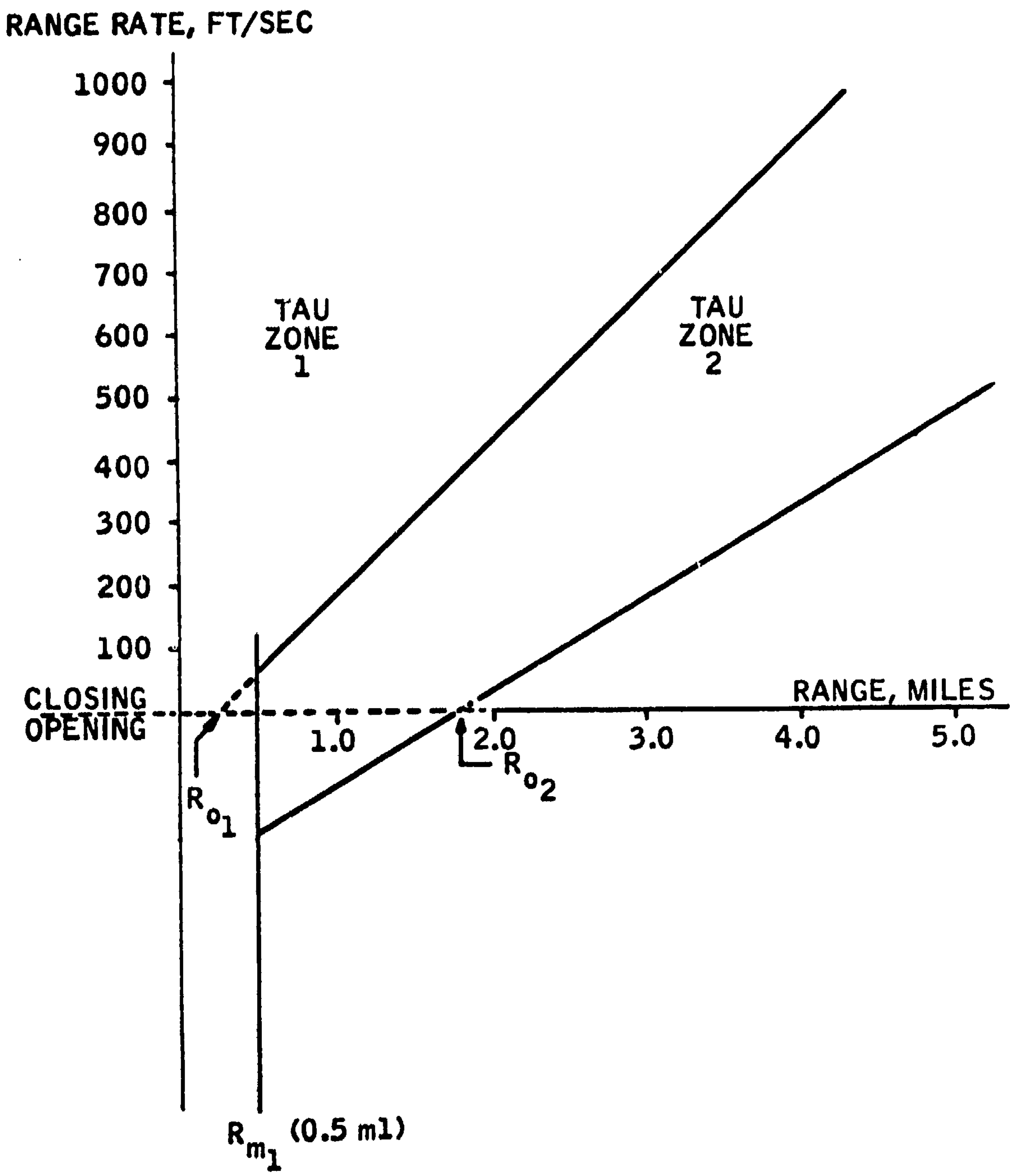


Figure 19. AVOID I Threat Zones.

COMMUNICATION RANGE AND RELIABILITY TESTS

The objective of this type of flight was to determine the effective communication range and reliability as a function of encounter angle. This data was then compared with the data accumulated during flight tests of the AVOID I system. The AVOID I and AVOID II should have similar patterns. There may be some differences in the AVOID II pattern since all signals are transmitted through both antennas. The AVOID I replies through both antennas only when the received interrogations are below a specific signal level.

The communication range was expressed as a function of the level of communication reliability. The number of tracking sequences which occur during each encounter were determined and compared with the number of successfully completed tracks. The ranges at which various communication reliabilities were achieved could then be accumulated.

The communication reliability for various encounter angles was determined for threatening target tracks. In addition, separate reliabilities for the CAS display, Tau-1 threat zone, and Tau-2 threat zone were compiled. Figure 19 shows the encounter pattern which was flown to establish the communication range and reliability of the AVOID II.

SENSOR ACCURACY TESTS

In order to achieve a high probability of no missed alarms and to minimize false alarms, the AVOID II equipment must be able to measure the range rate of and range to intruders with the following effective accuracies:

Range: Mean error less than 300 ft (91 m)
Standard deviation less than 300 ft (91 m)

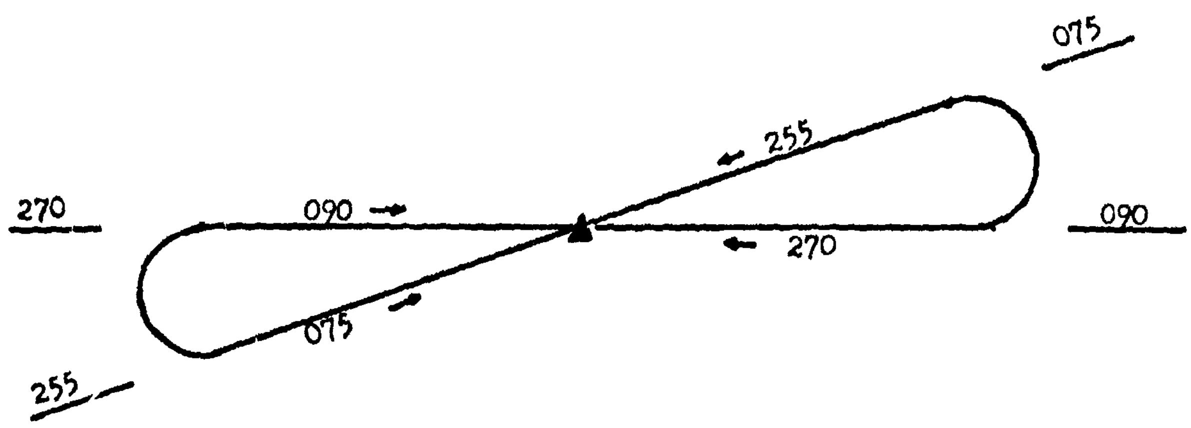
Range rate: Mean error less than 10 kn (5.1 m/s)
Standard deviation less than 30 kn (15.4 m/s)

During tests of the AVOID II Tau threat processing accuracy, the minimum instrumentation accuracy of the ground track was:

Range: 50 ft (1 sigma) (15.2 m)
Range rate: 2 kn (1 sigma) (1.03 m/s)

Due to the nature of the AVOID CAS signal processing, the presence of random reply signals can affect the accuracy of the Tau threat processing. The result is that an intruder sometimes appears to be a more severe Tau threat (lower Tau). This means that with significant amounts of random reply and interrogation signals injected into the r-f link, intruders will appear to have slightly larger range rates. The magnitude or severity of this effect can be determined by injecting random signals (AVOID replies and interrogations) representative of various air traffic situations, including the worst case density of the Mitre model (or snapshot) of the Los Angeles area for 1982.

HEAD - ON



TAIL CHASE

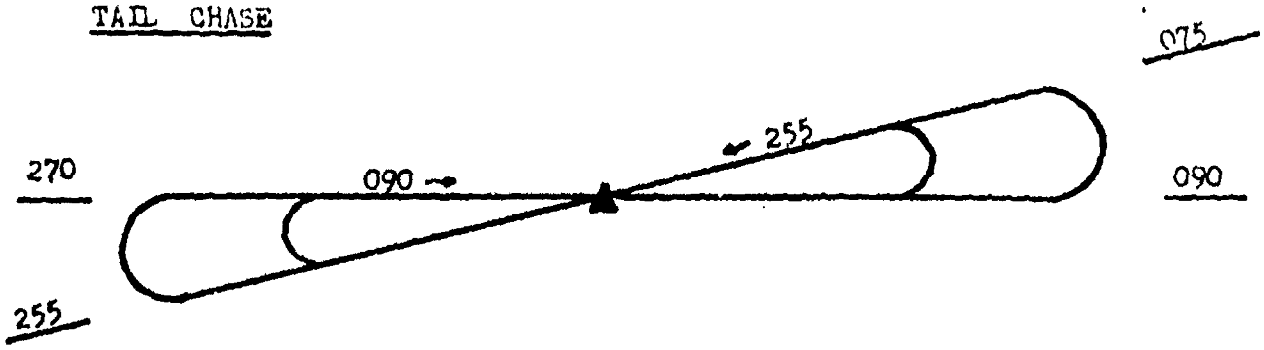
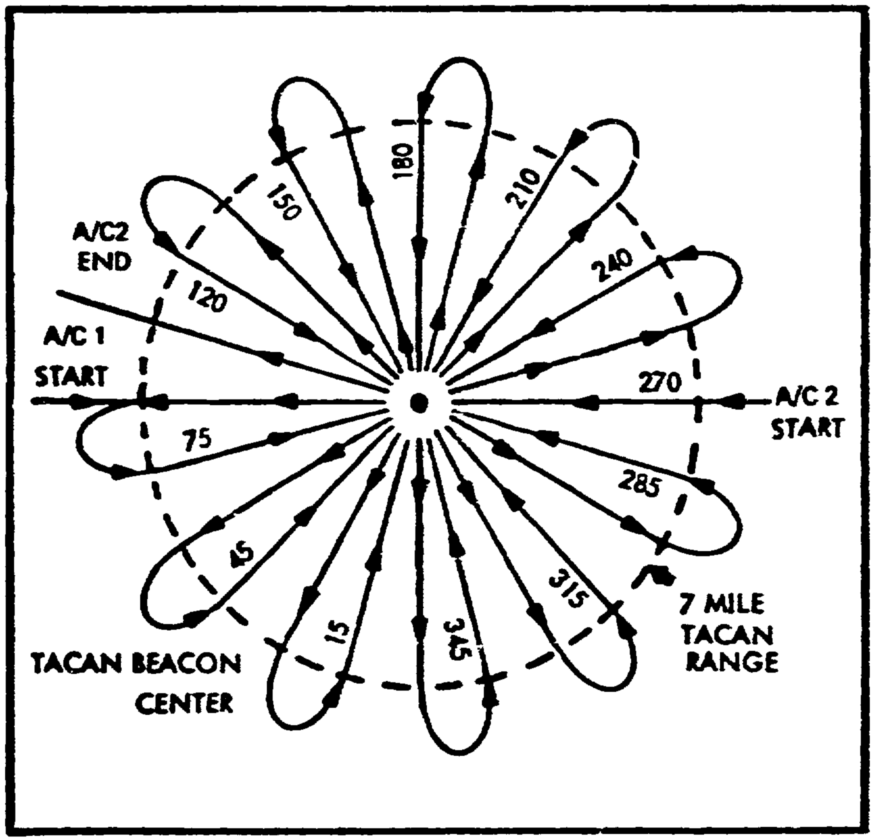


Figure 20. Figure Eight Pattern.



ENCOUNTER NUMBER	COURSE FLOWN		ANGLE BETWEEN RADIALS (DEG)
	A/C 1	A/C 2	
1	90	270	180
2	255	75	180
3	90	240	150
4	255	45	150
5	90	210	120
6	255	15	120
7	90	180	90
8	255	345	90
9	90	150	60
10	255	315	60
11	90	120	30
12	255	285	30
13	90	90	0

Figure 21. Single Daisy Encounter Pattern.

TABLE III. PREDICTED INTERROGATION AND FRUIT ENVIRONMENT FOR AVOID CAS IN 1982 LOS ANGELES BASIN

CAS	CENTER	POWER BUDGET	INTERROGATIONS RECEIVED	RESPONSES RECEIVED	TOTAL PULSES REC.	TOTAL FRUIT INCL. MULTIPATH	FRUIT NORMAL TO 800 A/C.
AVOID-I	LA BASIN	BASELINE	938	12,634	16,386	21,302	24,710
AVOID-I	EAST 15 SOUTH 10	BASELINE	1403	21,437	27,049	35,164	40,790
AVOID-I	EAST 15 SOUTH 10	+2dB	2004	44,184	52,198	67,858	78,715
AVOID-II	LA BASIN	BASELINE	572	7,796	10,084	13,109	15,207
AVOID-II	EAST 15 SOUTH 10	BASELINE	649	10,514	13,110	17,043	19,770
AVOID-II	EAST 15 SOUTH 10	+2dB	1151	26,957	31,559	41,027	47,592

BASIC ENCOUNTER PATTERN

In order to accomplish the objectives of the AVOID II flight test evaluation, different aircraft encounter patterns were devised. The patterns were designed to test the Tau threat processing, altitude zone boundaries and altitude discrimination, compatibility of AVOID II with AVOID I, and the communication range and reliability. Normally this involved synchronization of the participating aircraft by the specification of air speed, altitude, heading, and range and bearing from a TACAN ground station. In order to simplify the synchronization process as well as provide a basis for relatively controlled encounter situations, two flight profiles were developed in reference to a TACAN ground station. One outline is that of a figure 8 and the other is that of a daisy. The figure 8 is accomplished in the following manner: an aircraft flies inbound to the station from the west with a TACAN bearing of 90 degrees, passes the TACAN ground station, continues eastward with a bearing of 270 degrees until reaching a predetermined range outbound at which time the aircraft executes a 180-degree left turn, which positions the aircraft on a radial displaced 15 degrees from the previous radial. At this time the TACAN bearing is 255 degrees. Again the aircraft flies inbound, crosses over the TACAN ground station, and continues outbound now with a TACAN bearing of 75 degrees. However, after reaching the predetermined distance from the TACAN station, the aircraft now executes a 180-degree right turn and resumes its original course eastward with the 90-degree TACAN bearing. Figure 20 shows an east/west oriented figure 8. The predetermined turn distances are dependent upon the air speeds of the aircraft involved, and can be adjusted during flight to compensate for wind conditions. The daisy pattern is accomplished in a fashion similar to the figure 8. Unlike the figure 8, the daisy pattern consists of successive 180-degree left turns which position the aircraft 15 degrees from the previous radial. When the two patterns are combined (with an altitude separation to insure safety of flight), the encounters occur in pairs, each pair being displaced by 30 degrees from the previous pair. Head-on encounters are considered to be 180-degree encounters and tail chases are considered to be 0-degree encounters. Figure 21 shows the daisy pattern superimposed over a figure 8 and lists the angles involved during the first 13 encounters of the full 24 encounter daisy.

When three aircraft participated in collision encounters two of the aircraft flew figure 8 patterns displaced by 180 degrees (head-on), while the third aircraft (P-3A) flew a daisy pattern. Thus, the P-3A generated the complete set of encounter angles with each of the other two aircraft, while they flew repeated 180-degree encounters with each other.

SIMULATED AIR TRAFFIC ENVIRONMENT DURING FLIGHT TESTS

The results of the study conducted by Honeywell to determine the interrogation and fruit rates expected in the Los Angeles Basin in 1982 are shown in table III. In determining these values the following assumptions were made:

1. All IFR aircraft were equipped with the AVOID I CAS (ANTC-117), approximately 15 percent of total.

2. VFR aircraft were equipped with the AVOID II, approximately 85 percent of total.

The baseline air traffic model used was Snapshot 1, as described in the Mitre Corporation Report[5]. This model contains a total of 743 aircraft. Based upon this environment and the communication ranges of the AVOID I and AVOID II, the average interrogation rates (transmitted and received) for each equipment were calculated. The transponder blockage and false alarm rates were then estimated from received fruit and interrogation rates. These values are presented in table IV.

During the majority of flight tests of the AVOID II, the traffic simulators aboard the aircraft were set to yield fruit and interrogation rates consistent (as close as possible) with the values determined by Honeywell. These values are:

	Interrogations Per Second	Replies (Switch Setting) Per Second
AVOID I	1536	~70,000 (64,000)
AVOID II	1536	~40,000 (32,000)

COMMUNICATION RELIABILITY

INTRODUCTION

The reliability of the information displayed to the pilot is a highly significant factor in determining the effectiveness of a collision avoidance system. The display reliability is a direct result of the communication reliability. In order to enhance the reliability of the pilot's display indications, the AVOID II equipment utilizes a display logic which requires two consecutive and consistent threat evaluations in order to generate a change on the pilot's display. That is, the results of the threat processing during successive rounds of communication are compared. If the target threat levels identified are the same, and the intruder tracking measurements occurring during the separate sequences correlate in range, then an enable signal is generated allowing an advisory or command to be displayed to the pilot. Similarly, in order to extinguish the pilot's display, the threat level identifications must be absent for two successive communication sequences, resulting in the generation of a signal which resets the pilot's display. This display logic precludes the generation of threat indications resulting from two fruit tracks (false alarm) or one fruit track followed by a legitimate track (early alarm). In addition, the display reliability is not affected by single failures in communication or processing. The success of the tracking and the threat processing on an individual communication round basis are nevertheless the important parameters in evaluating the reliability of the collision avoidance

[5]Statistical Summary of the 1982 Los Angeles Basin Standard Traffic Model. April 1973. MTR-6387.

TABLE IV. PREDICTED AVOID CAS OPERATION IN DENSE TRAFFIC ENVIRONMENT

	AVOID-I	AVOID-II
Average Interrogations Transmitted per second	11.0	9.4
Average Interrogations Received per second	2158	1240
Fruit Pulses Received per second	78,715	47,592
Probability of Response (single Interrogation)	0.92815	0.96000
Probability of Response (one or more of three interrogations)	0.99963	0.999936
Probability of Detecting Threat (First Set)	[2] 0.983	[3] 0.995
Probability of Detecting Threat (Remaining Sets)	[2] 0.997	[3] 0.9995
Probability of False Alarm (per altitude band per sequence)	6.325×10^{-8}	7.12×10^{-11}
Hours per False Alarm (all bands)	8000	7.2×10^{6}
Hours per False Alarm (co-altitude)	1.3×10^{6}	1.2×10^{9}

Notes: 1) These results are based on an aircraft at an altitude of 5000 feet in the highest density region of the Los Angeles Basin with the loop sensitivity 2 db above nominal.

2) The probability of an AVOID-I or an AVOID-II detecting an AVOID-I.

3) The probability of an AVOID-I or an AVOID-II detecting an AVOID-II.

system, since the display logic is completely dependent on the threat evaluations and associated range measurements.

The communication reliability was established on the basis of operational accuracies during each individual round of communications once the aircraft attained the communication range of the collision avoidance equipments. Although the AVOID II transmitter power combined with its receiver sensitivity yields a communication range of approximately 8.4 nautical miles (15.6 kilometres) between two AVOID II equipped aircraft, the range measurement devices employed in the hardware allowed the evaluation of aircraft responses originating within a range of 4.2 nautical miles (7.8 km). The effects of this communication range on warning times are discussed in more detail in the next section titled "AVOID I - AVOID II COMPATIBILITY."

A communication round consists of the successive interrogation sets (one set each 0.5 second) during a 3.5-second period together with the response processing which occurs at the end of the interrogation sequence. An interrogation set as performed by the AVOID II occurs every 0.5 second and spans a total of 2500 feet (762 m) of altitude. Each set consists of several interrogations of overlapping 1300-foot (396 m) altitude bands. The sequence of interrogations for an AVOID II equipment is shown in figure 22. The basic interrogation bands are the I (+6) and the I (-6). Together they span the total 2500-feet (762 m) of altitude covered by the AVOID II. Their primary function is the detection of aircraft within tracking range. The I (+6) interrogations are coded to illuminate aircraft within -50 feet and +1250 feet of altitude relative to the interrogating aircraft's altitude. Similarly the I (-6) interrogations cover a band from +50 feet to -1250 feet of relative altitude. Upon receipt of replies correlated in range during the first three interrogation sets of the full 3.5-second sequence, additional altitude bands are interrogated. The additional bands are coded to permit resolution of the various altitude threat zone boundaries to within the required 100 feet. The additional bands are referred to as the I (0), the I (+4), and the I (-4). Successive responses to the I (0) band interrogations, which cover -650 feet (198 m) to +650 feet of relative altitude, result in the identification of a potential coaltitude threat. Similar responses to either the I (+4) or I (-4) band interrogations in addition to the I (0) band interrogations indicate that a threatening aircraft is within +400 feet (122 m) or -400 feet relative altitude respectively, and that altitude biasing in the direction of an impending maneuver is required[4]. Successful communication of aircraft altitude is dependent upon the reliable reception of responses to the five I (0), I (+4), and I (-4) interrogation triplets each sequence.

The quantity used as a measure of the communication reliability was the number of successfully completed rounds divided by the total number of rounds which should occur during an encounter between two aircraft. Reliabilities of this sort were determined for the various levels of threat processing associated with the different aspects of the flight test encounters. Reliabilities were normally distinguished on the basis of initial altitude separation, tau threat

[4]Air Transport Association of America ANTC Report No. 117, Revision 10, of 27 September 1971 - Airborne Collision Avoidance Requirements.

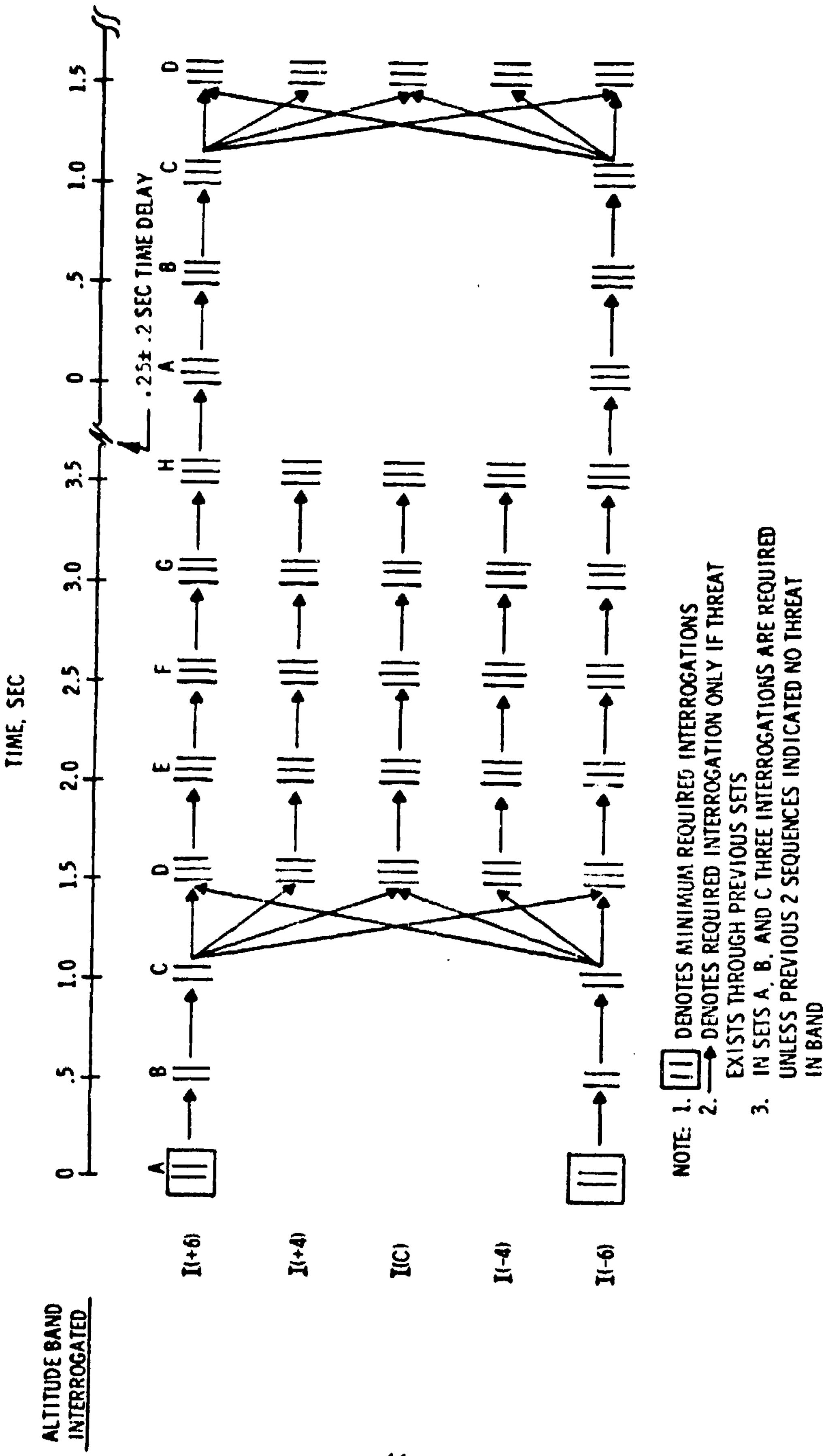


Figure 22. AVOID II Altitude Band Interrogation Sequence.

status, and encounter angle. Variations in communication reliabilities as a function of tau threat status and encounter angle were the result of changing signal strength and possible antenna interference effects. Variations in communication reliability as a function of altitude separation were the result of the additional number of successful responses required for co-altitude (within ±600 feet (198 m) altitude) threat identifications and co-altitude requiring bias (within ±400 feet (122 m) altitude) threat identifications.

In order to detect a co-altitude aircraft, responses to the I (0) and either the I (+6) or the I (-6) band interrogations must be received successfully during the 3.5-second interrogation sequence. Identification of a nonco-altitude aircraft requires only the successful reception of either the I (-6) or the I (+6) interrogation band responses, depending on the relative altitude of the aircraft [I (-6) for aircraft up to 1200 feet below and I (+6) for those up to 1200 feet (365.8 m) above.] Nonco-altitude threats thus have the least stringent requirements for success. Equal altitude detection will have a lower reliability for equivalent circumstances since responses to all interrogation bands [I (+6), I (-6), I (0), I (+4) and I (-4)] are necessary.

It is necessary to evaluate the ability of a collision avoidance equipment to provide the pilot with correct information, from the maximum tracking range up to the closest point of approach, when no evasive action is taken or up to the clear point when evasive maneuvers are employed. In regard to tau threat status (range divide by closure rate), the data was grouped into two main categories; one was the tau-1 threat situations resulting in commands, and the other was the tau-2 threat situations resulting in vertical speed limitations (advisories). In addition, the reliability of the overall target tracking was established for comparison with the individual threat zones. After discussing the separate results of AVOID II versus AVOID II flights, a summary of all the reliability results is presented, indicating the overall performance characteristics of the AVOID II.

AVOID II VS AVOID II ENCOUNTERS

This section discusses the round and display reliabilities established during flight encounters between the NC-117 and the P-3A aircraft. Both aircraft were equipped with the AVOID II system. The major portion of the data was accumulated during execution of the daisy flight test pattern. The daisy pattern was described previously in the section titled "Flight Test Plan Summary." Additional information was collected during flights which consisted of head-on and tail chase encounters.

With the exception of flight 1, all flights were conducted with a simulated air traffic environment in excess of Honeywell predictions for the AVOID CAS in the Los Angeles Basin in 1982. During flight 1, head-on encounters were flown without fruit, with the fruit predicted for the Los Angeles Basin in 1982, and with almost twice the predicted amount. The predictions for the AVOID II environment specify 1536 random interrogations per second and about 40,000 random replies per second. A portion of flight 1 was conducted with more than 64,000 random replies per second injected at the antenna port of each AVOID II

equipment. Table V contains the round reliability and display reliability results for flight 1. The first four encounters were flown with an altitude separation of 1000 feet (305 m) while equipment operation was verified; the remaining head-on encounters were flown with an altitude separation of less than 600 feet (183 m). Aboard the P-3A during the ninth encounter, an intermittent malfunction occurred in which the equipment did not initiate interrogations but did respond to the interrogations of the other aircraft. The problem was later corrected by the replacement of several possibly defective components. During flight 1, eight tail chase encounters were flown at the various altitude separations shown in order to test the ability of the AVOID II equipment to accurately identify the altitude threat zones. The higher fruit conditions generated during part of the test had no apparent effect on the system operation. This result was consistent with the results obtained during laboratory testing, which showed successful AVOID II operation at fruit levels at least twice those predicted for the Los Angeles Basin in 1982.

The round reliability for head-on encounters at different closing rates is compared in table VI, which shows the results obtained during flight 2 on June 30, 1975. The head-on encounters during flight 2 were conducted with an initial altitude separation of less than 500 feet (152 m). The majority of encounters were started with a 400-foot (122 m) altitude separation, which required the equipment to generate an altitude bias. Eight encounters were flown with air speeds which resulted in closure rates of approximately 350 knots (180 m/s), and another eight were flown with speeds resulting in 425-knot (219 m/s) closure rates. During the head-on co-altitude encounters, collision avoidance maneuvers displayed to the pilot by the equipment were performed. Data accumulated aboard the NC-117 is not included in the figures. It was not possible to include the NC-117 data pertaining to flight 2 due to a failure of the digital tape recorder aboard the NC-117 during the flight. In addition to the head-on encounters, tail chase encounters were again flown to determine the ability of the AVOID II to identify altitude threat zones. Tail chase encounters were ideal for altitude boundary tests, since the aircraft remained within communication range for a longer period of time and the flight parameters were easier to control due to the reduced closure rates involved.

The various reliabilities, as a function of encounter angle, during flight 3 on July 1, 1975 are shown in table VII. Initial altitude separation for all encounters during flight 3 was less than 500 feet (152 m). The closure rates varied from approximately 360 knots (185 m/s) at the head-on or 180-degree encounter angle to approximately 60 knots (31 m/s) at the tail chase or 0-degree encounter angle. The reduced number of tracks which occur at the larger encounter angles is the direct result of the relatively short amount of time the two aircraft spend within communication tracking range, which is limited to 4.2 nautical miles (7.8 km), and is not the result of differences in communication link sensitivity or antenna patterns. A problem similar to that which occurred during flight 2 resulted in a lack of flight data aboard the NC-117 during flight 3.

During flight 3, the display reliability was 100 percent. That is, the correct indication was displayed to the pilot every round during all encounters flown. The round target tracking reliability was 100 percent for all encounters flown with the exception of the +60, +30, -30, and -120 degree encounter angles.

TABLE V. INTRUDER TRACKING AND DISPLAY RELIABILITY, FLIGHTS 1 & 2

	Display Reliability	Intruder Tracking Reliability
P-3A Flight 1	$\frac{381}{381} = 1.00$	$\frac{888}{899} = 0.988$
NC-117 Flight 1	$\frac{186}{188} = 0.989$	$\frac{454}{464} = 0.978$
P-3A Flight 2	$\frac{600}{603} = 0.995$	$\frac{911}{925} = 0.985$

TABLE VI. INTRUDER TRACKING RELIABILITY DURING HEAD-ON ENCOUNTERS AT DIFFERENT CLOSURE RATES

Mean Range Rate (knots)	360	430
P-3A Flight 1	$\frac{40}{40} = 1.00$	$\frac{55}{55} = 1.00$
NC-117 Flight 1	$\frac{40}{40} = 1.00$	$\frac{63}{65} = 0.969$
P-3A Flight 2	$\frac{70}{70} = 1.00$	$\frac{39}{40} = 0.975$
Total	$\frac{150}{150} = 1.00$	$\frac{157}{160} = 0.981$

TABLE VII. COMMUNICATION RELIABILITY AS A FUNCTION OF ENCOUNTER ANGLE, FLIGHT 3, P-3A

Encounter Angle (deg)	180	150	120	90	60	30	0	-30	-60	-90	-120	-150
P-3A Display Reliability	$\frac{40}{40}$	$\frac{39}{39}$	$\frac{25}{25}$	$\frac{19}{19}$	$\frac{17}{17}$	$\frac{20}{20}$	$\frac{44}{44}$	$\frac{27}{27}$	$\frac{27}{27}$	$\frac{16}{16}$	$\frac{24}{24}$	$\frac{21}{21}$
P-3A Round Reliability	$\frac{40}{40}$	$\frac{39}{39}$	$\frac{25}{25}$	$\frac{32}{32}$	$\frac{52}{54}$	$\frac{64}{74}$	$\frac{89}{89}$	$\frac{63}{66}$	$\frac{40}{40}$	$\frac{31}{31}$	$\frac{23}{24}$	$\frac{21}{21}$
P-3A TAU-1 Reliability	$\frac{22}{22}$	$\frac{21}{21}$	$\frac{11}{11}$	$\frac{3}{3}$	$\frac{5}{5}$	$\frac{6}{6}$	$\frac{10}{10}$	$\frac{10}{10}$	$\frac{10}{10}$	$\frac{10}{11}$	$\frac{8}{8}$	$\frac{8}{8}$
P-3A TAU-2 Coalt. Reliability	$\frac{8}{8}$	$\frac{9}{9}$	$\frac{8}{8}$	$\frac{12}{12}$	$\frac{6}{6}$	$\frac{9}{9}$	$\frac{9}{9}$	$\frac{6}{6}$	$\frac{8}{8}$	$\frac{8}{8}$	$\frac{6}{7}$	$\frac{5}{5}$

	Display	Round	TAU-1	TAU-2
Overall Reliability P-3A	$\frac{319}{319}$	$\frac{519}{535}$	$\frac{124}{125}$	$\frac{94}{95}$
	1.00	0.970	0.992	0.989

The poorest round reliability which occurred was 86.5 percent at the +30-degree encounter angles. The overall round reliability for all encounters of flight 3 without regard to encounter angle was 97.0 percent. The Tau-1 and Tau-2 co-altitude reliabilities were 100 percent except for the -90-degree encounter angle for Tau-1 threats and the -120-degree encounter angle for Tau-2 co-altitude threats. The overall Tau-1 and Tau-2 co-altitude reliabilities were 99.2 and 98.9 percent respectively.

In a similar manner, tables VIII through XII show the communication reliabilities established during flight 4 on July 2 and flight 5 on July 3 of 1975. Flight 4 was designed to collect reliability data as a function of encounter angle. Flight 5 consisted of a daisy encounter pattern and additional tail chase encounters in order to obtain more data in regard to the AVOID II ability to determine altitude separation for accurate threat evaluation. Initial altitude separation during the daisy portions of both flights was 400 feet (122 m) with a few exceptions when the separation was 500 feet (152 m).

The display reliability during flight 4 was 100 percent for all encounter angles except the 90-degree encounter angle for the NC-117 and the -60-degree encounter angle for the P-3A. The overall display reliabilities without regard to encounter angle were 99.3 percent for both the NC-117 and the P-3A. The round reliability aboard the NC-117 for flight 4 is shown at the top of table IX. The corresponding round reliability results which occurred aboard the P-3A are shown below those of the NC-117. The poorest round reliability during flight 4 occurred at the -60-degree encounter angle which resulted in a 91.3 percent reliability. The overall round reliability without respect to encounter angle was 95.6 percent for the NC-117 and 95.8 percent for the P-3A.

The Tau-1 and Tau-2 coaltitude reliabilities as a function of encounter angle for flight 4 are shown in table X. These reliabilities during flight 4 were 100 percent for all encounter angles except for the 90-degree encounter angle aboard the NC-117. The overall Tau-2 reliability for both aircraft was 100 percent. The overall TAU-1 reliability was 100 percent aboard the P-3A and 99.0 percent aboard the NC-117.

Flight 5 consisted of daisy encounter angles between 180 degrees and 0 degrees, and did not include the additional angles from -30 degrees to -150 degrees. The display reliability for flight 5 was 100 percent for all encounter angles except the 120-degree encounters aboard the NC-117 and the 90-degree encounters aboard the P-3A. The overall display reliability without regard to encounter angle was 96.6 percent aboard the NC-117 and 98.4 percent aboard the P-3A. Both the display reliability and round reliability figures are contained in table XI. As indicated, the round reliability during flight 5 was 100 percent for the 180-, 150-, and 120-degree encounter angles. The reliability during the remaining encounter angles was less with the poorest round reliability being 86.7 percent during the 90-degree encounters aboard the P-3A. The overall round reliabilities without regard to encounter angle for flight 5 were 93.9 percent for the NC-117 and 94.7 percent for the P-3A. The closest point of approach during the 30-degree encounters was not small enough to generate a Tau-2 or Tau-1 threat, with the result that no pilot display indications were required. Consequently, the tables which list the various reliabilities during flight 5 contain only round reliability data for the 30-degree encounter angles.

TABLE VIII. DISPLAY RELIABILITY AS A FUNCTION OF ENCOUNTER ANGLE, FLIGHT 4, P-3A VS NC-117

Encounter Angle (deg)	180	150	120	90	60	30	0	-30	-60	-90	-120	-150
NC-117 Display Reliability	$\frac{38}{38}$ 1.00	$\frac{21}{21}$ 1.00	$\frac{25}{25}$ 1.00	$\frac{25}{27}$ 0.926	$\frac{12}{12}$ 1.00	$\frac{15}{15}$ 1.00	$\frac{43}{43}$ 1.00	$\frac{20}{20}$ 1.00	$\frac{25}{25}$ 1.00	$\frac{25}{25}$ 1.00	$\frac{23}{23}$ 1.00	$\frac{21}{21}$ 1.00
P-3A Display Reliability	$\frac{36}{36}$ 1.00	$\frac{20}{20}$ 1.00	$\frac{25}{25}$ 1.00	$\frac{25}{25}$ 1.00	$\frac{12}{12}$ 1.00	$\frac{16}{16}$ 1.00	$\frac{44}{44}$ 1.00	$\frac{19}{19}$ 1.00	$\frac{23}{25}$ 0.920	$\frac{24}{24}$ 1.00	$\frac{23}{23}$ 1.00	$\frac{10}{10}$ 1.00
Combined Display Reliability	$\frac{74}{74}$ 1.00	$\frac{41}{41}$ 1.00	$\frac{50}{50}$ 1.00	$\frac{50}{52}$ 0.962	$\frac{24}{24}$ 1.00	$\frac{31}{31}$ 1.00	$\frac{87}{87}$ 1.00	$\frac{39}{39}$ 1.00	$\frac{48}{50}$ 0.960	$\frac{49}{49}$ 1.00	$\frac{46}{46}$ 1.00	$\frac{31}{31}$ 1.00

	P-3A	NC-117	P-3A & NC-117
Overall Display Reliability	$\frac{277}{279} = 0.993$	$\frac{293}{295} = 0.993$	$\frac{570}{574} = 0.993$

TABLE IX. ROUND (INTRUDER TRACKING) RELIABILITY AS A FUNCTION OF ENCOUNTER ANGLE, FLIGHT 4

Encounter Angle (deg)	180	150	120	90	60	30	0	-30	-60	-90	-120	-150
NC-117 Round Reliability	$\frac{39}{39}$	$\frac{21}{21}$	$\frac{24}{24}$	$\frac{33}{33}$	$\frac{46}{48}$	$\frac{73}{78}$	$\frac{101}{110}$	$\frac{95}{100}$	$\frac{42}{46}$	$\frac{29}{29}$	$\frac{24}{24}$	$\frac{21}{21}$
	1.00	1.00	1.00	1.00	0.958	0.936	0.918	0.950	0.913	1.00	1.00	1.00
P-3A Round Reliability	$\frac{38}{38}$	$\frac{20}{20}$	$\frac{25}{25}$	$\frac{31}{32}$	$\frac{46}{47}$	$\frac{74}{78}$	$\frac{104}{112}$	$\frac{94}{100}$	$\frac{44}{47}$	$\frac{28}{29}$	$\frac{24}{24}$	$\frac{19}{19}$
	1.00	1.00	1.00	0.969	0.979	0.949	0.929	0.940	0.936	0.966	1.00	1.00
Combined NC-117 & P-3A Round Reliability	$\frac{77}{77}$	$\frac{41}{41}$	$\frac{49}{49}$	$\frac{64}{65}$	$\frac{92}{95}$	$\frac{147}{156}$	$\frac{205}{222}$	$\frac{189}{200}$	$\frac{86}{93}$	$\frac{57}{58}$	$\frac{48}{48}$	$\frac{40}{40}$
	1.00	1.00	1.00	0.985	0.968	0.942	0.923	0.945	0.925	0.983	1.00	1.00

	NC-117	P-3A	NC-117 & P-3A
Overall Round Reliability	$\frac{548}{573} = 0.956$	$\frac{547}{571} = 0.958$	$\frac{1095}{1144} = 0.957$

TABLE X. TAU-1 AND TAU-2 EVALUATION RELIABILITY AS A FUNCTION OF ENCOUNTER ANGLE, FLIGHT 4

Encounter Angle (deg)	180	150	120	90	60	30	0	-30	-60	-90	-120	-150
NC-117 TAU-1	16/16	9/9	5/5	11/12	4/4	3/3	12/12	1/1	5/5	11/11	9/9	10/10
Reliability	1.00	1.00	1.00	0.917	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P-3A TAU-1	20/20	8/8	11/11	10/10	5/5	4/4	13/13	-	5/5	11/11	11/11	12/12
Reliability	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00
NC-117 TAU-2	12/12	5/5	7/7	8/8	4/4	4/4	12/12	10/10	15/15	7/7	6/6	5/5
Reliability	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P-3A TAU-2	5/5	4/4	8/8	7/7	4/4	5/5	13/13	10/10	11/12	8/8	5/5	3/3
Reliability	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE XI. DISPLAY AND INTRUDER TRACKING RELIABILITY AS A FUNCTION OF ENCOUNTER ANGLE, FLIGHT 5

Encounter Angle (deg)	180	150	120	90	60	30	0
NC-117 Display Reliability	$\frac{18}{18}$ 1.00	$\frac{18}{18}$ 1.00	$\frac{16}{18}$ 1.00	$\frac{21}{21}$ 1.00	$\frac{24}{26}$ 0.923	-	$\frac{19}{19}$ 1.00
P-3A Display Reliability	$\frac{18}{18}$ 1.00	$\frac{20}{20}$ 1.00	$\frac{21}{21}$ 1.00	$\frac{20}{22}$ 1.00	$\frac{27}{27}$ 1.00	-	$\frac{18}{18}$ 1.00
NC-117 Round Reliability	$\frac{19}{19}$ 1.00	$\frac{19}{19}$ 1.00	$\frac{21}{21}$ 1.00	$\frac{25}{26}$ 0.962	$\frac{45}{47}$ 0.957	$\frac{71}{80}$ 0.888	$\frac{31}{34}$ 0.912
P-3A Round Reliability	$\frac{19}{19}$ 1.00	$\frac{20}{20}$ 1.00	$\frac{22}{22}$ 1.00	$\frac{26}{30}$ 0.867	$\frac{45}{46}$ 0.978	$\frac{86}{93}$ 0.925	$\frac{31}{33}$ 0.939

	NC-117		P-3A	
	Display	Round	Display	Round
Overall Reliability	$\frac{116}{120} = 0.966$	$\frac{231}{246} = 0.939$	$\frac{124}{126} = 0.984$	$\frac{249}{263} = 0.947$

TABLE XII. TAU-1 AND TAU-2 EVALUATION RELIABILITIES AS A FUNCTION OF ENCOUNTER ANGLE, FLIGHT 5

Encounter Angle (deg)	180	150	120	90	60	30	0
NC-117 TAU-1	$\frac{10}{10}$	$\frac{9}{9}$	$\frac{10}{11}$	$\frac{8}{8}$	$\frac{10}{12}$	-	$\frac{6}{6}$
Reliability	1.00	1.00	0.909	1.00	0.833		1.00
P-3A TAU-1 Coalt.	$\frac{14}{14}$	$\frac{9}{9}$	$\frac{11}{11}$	$\frac{8}{8}$	$\frac{10}{10}$	-	$\frac{4}{4}$
Reliability	1.00	1.00	1.00	1.00	1.00		1.00
NC-117 TAU-2 Coalt.	$\frac{3}{3}$	$\frac{3}{3}$	$\frac{5}{6}$	$\frac{8}{8}$	$\frac{8}{9}$	-	$\frac{3}{3}$
Reliability	1.00	1.00	0.833	1.00	0.889		1.00
P-3A TAU-2 Coalt.	$\frac{4}{4}$	$\frac{4}{4}$	$\frac{6}{6}$	$\frac{6}{8}$	$\frac{10}{10}$	-	$\frac{4}{4}$
Reliability	1.00	1.00	1.00	0.750	1.00		1.00

	NC-117 TAU-1	NC-117 TAU-2	P-3A TAU-1	P-3A TAU-2
Overall Reliability	$\frac{53}{56} = 0.946$	$\frac{30}{32} = 0.938$	$\frac{56}{56} = 1.00$	$\frac{34}{36} = 0.944$

Table XII shows the Tau-1 and Tau-2 co-altitude reliabilities as a function of encounter angle for flight 5. The overall Tau-1 reliability was 100 percent for the P-3A and 94.6 percent for the NC-117. The overall Tau-2 co-altitude reliability was 94.4 percent for the P-3A and 93.8 percent for the NC-117.

Flight 8 consisted of a daisy encounter pattern involving three aircraft. Table XIII contains the display and round reliability results as a function of encounter angle. The reliabilities shown are the results of communications between the two AVOID II equipped aircraft participating in the flight. The NC-117 and P-3A were equipped with the AVOID II CAS equipment while the RA-3B was equipped with an AVOID I CAS. Additional information regarding this three aircraft encounter pattern is contained in the section which discusses AVOID II - AVOID I compatibility.

The AVOID I equipped RA-3B flew a figure 8 pattern at an altitude of 10,500 feet, the P-3A flew the daisy pattern at an altitude of 9,700 feet, and the NC-117 flew a figure 8 pattern at an altitude of 9,300 feet which resulted in head-on or 180-degree encounter angles with respect to the RA-3B. Maneuver indications displayed to the pilots by the CAS equipments during flight 8 were not followed.

The display reliabilities were 100 percent for all encounter angles aboard the P-3A and 100 percent for all encounter angles except the -90-degree encounter angle aboard the NC-117. The overall display reliability without regard to encounter angle during flight 8 was 99.7 percent for the NC-117 and 100 percent for the P-3A. The poorest round reliability during flight 8 occurred during the tail chase encounters. Aboard the NC-117, the tail chase round reliability was 89.3 percent while the overall round reliability without regard to encounter angle was 96.9 percent. Aboard the P-3A, the tail chase round reliability was 91.2 percent and the overall round reliability was 96.8 percent.

Flight 8 Tau-1 and Tau-2 coaltitude threat evaluation reliabilities as a function of encounter angle are shown in table XIV. The Tau-1 reliabilities aboard the NC-117 were 100 percent with the exception of the 150-degree encounter angle. The overall Tau-1 evaluation reliability aboard the NC-117 was 99.5 percent. The Tau-1 reliability aboard the P-3A during flight 8 was 100 percent for all encounter angles. The overall Tau-2 coaltitude threat evaluation reliabilities during flight 8 were 98.9 percent for both the NC-117 and the P-3A.

Reliabilities established by the AVOID II equipped aircraft during the three aircraft encounters of flight 8 were consistent with the reliabilities established by the same aircraft during the two aircraft encounters.

COMMUNICATION RELIABILITY SUMMARY

The reliabilities established during daisy flight test encounters between AVOID II equipped aircraft were satisfactory in every aspect. Table XV shows the various reliabilities established aboard the P-3A as a function of the encounter angle between aircraft. The values shown represent the results of all flight test date recorded during encounters involving two AVOID II equipped

TABLE XIII. DISPLAY AND INTRUDER TRACKING RELIABILITIES AS A FUNCTION OF ENCOUNTER ANGLE, FLIGHT 8

Encounter Angle (deg)	180	150	120	90	60	30	0	-30	-60	-90	-120	-150
NC-117 Display Reliability	$\frac{39}{39}$ 1.00	$\frac{20}{20}$ 1.00	$\frac{22}{22}$ 1.00	$\frac{24}{24}$ 1.00	$\frac{25}{25}$ 1.00	$\frac{26}{26}$ 1.00	$\frac{33}{33}$ 1.00	$\frac{28}{28}$ 1.00	$\frac{25}{25}$ 1.00	$\frac{24}{25}$ 0.960	$\frac{23}{23}$ 1.00	$\frac{20}{20}$ 1.00
P-3A Display Reliability	$\frac{38}{38}$ 1.00	$\frac{21}{21}$ 1.00	$\frac{22}{22}$ 1.00	$\frac{22}{22}$ 1.00	$\frac{27}{27}$ 1.00	$\frac{28}{28}$ 1.00	$\frac{33}{33}$ 1.00	$\frac{28}{28}$ 1.00	$\frac{26}{26}$ 1.00	$\frac{27}{27}$ 1.00	$\frac{25}{25}$ 1.00	$\frac{20}{20}$ 1.00
NC-117 Round Reliability	$\frac{40}{40}$ 1.00	$\frac{19}{20}$ 0.950	$\frac{22}{22}$ 1.00	$\frac{28}{28}$ 1.00	$\frac{40}{40}$ 1.00	$\frac{69}{69}$ 1.00	$\frac{100}{112}$ 0.893	$\frac{72}{72}$ 1.00	$\frac{40}{41}$ 0.976	$\frac{27}{29}$ 0.931	$\frac{24}{24}$ 1.00	$\frac{20}{20}$ 1.00
P-3A Round Reliability	$\frac{40}{40}$ 1.00	$\frac{21}{21}$ 1.00	$\frac{26}{26}$ 1.00	$\frac{32}{33}$ 0.970	$\frac{51}{52}$ 0.981	$\frac{69}{71}$ 0.972	$\frac{93}{102}$ 0.912	$\frac{69}{71}$ 0.972	$\frac{39}{41}$ 0.951	$\frac{31}{31}$ 1.00	$\frac{25}{25}$ 1.00	$\frac{20}{20}$ 1.00

	NC-117		P-3A	
	Display	Round	Display	Round
Overall Reliability	$\frac{309}{310} = 0.997$	$\frac{501}{517} = 0.969$	$\frac{317}{317} = 1.00$	$\frac{516}{533} = 0.968$

TABLE XIV. TAU-1 AND TAU-2 EVALUATION RELIABILITIES AS A FUNCTION OF ENCOUNTER ANGLE, FLIGHT 8

Encounter Angle (deg)	180	150	120	90	60	30	0	-30	-60	-90	-120	-150
NC-117 TAU-1	$\frac{35}{35}$	$\frac{15}{16}$	$\frac{16}{16}$	$\frac{15}{15}$	$\frac{15}{15}$	$\frac{19}{19}$	$\frac{19}{19}$	$\frac{19}{19}$	$\frac{17}{17}$	$\frac{17}{17}$	$\frac{16}{16}$	$\frac{16}{16}$
Reliability	1.00	0.938	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P-3A TAU-1	$\frac{34}{34}$	$\frac{16}{16}$	$\frac{16}{16}$	$\frac{15}{15}$	$\frac{15}{15}$	$\frac{20}{20}$	$\frac{21}{21}$	$\frac{18}{18}$	$\frac{17}{17}$	$\frac{18}{18}$	$\frac{17}{17}$	$\frac{16}{16}$
Reliability	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
NC-117 TAU-2 Coalt.	$\frac{5}{5}$	$\frac{4}{4}$	$\frac{6}{6}$	$\frac{9}{9}$	$\frac{10}{10}$	$\frac{7}{7}$	$\frac{12}{12}$	$\frac{9}{9}$	$\frac{8}{8}$	$\frac{7}{8}$	$\frac{7}{7}$	$\frac{4}{4}$
Reliability	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.875	1.00	1.00
P-3A TAU-2 Coalt.	$\frac{6}{6}$	$\frac{5}{5}$	$\frac{6}{7}$	$\frac{7}{7}$	$\frac{12}{12}$	$\frac{8}{8}$	$\frac{12}{12}$	$\frac{10}{10}$	$\frac{8}{8}$	$\frac{8}{8}$	$\frac{8}{8}$	$\frac{4}{4}$
Reliability	1.00	1.00	0.857	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

	NC-117		P-3A	
	TAU-1	TAU-2	TAU-1	TAU-2
Overall Reliability	$\frac{219}{220} = 0.995$	$\frac{88}{89} = 0.989$	$\frac{223}{223} = 1.00$	$\frac{94}{95} = 0.989$

TABLE XV. COMMUNICATION RELIABILITY AS A FUNCTION OF ENCOUNTER ANGLE ABOARD THE P-3A

Encounter Angle (deg)	180	150	120	90	60	30	0	-30	-60	-90	-120	-150
P-3A Display Reliability	$\frac{132}{132}$	$\frac{100}{100}$	$\frac{93}{93}$	$\frac{86}{88}$	$\frac{83}{83}$	$\frac{64}{64}$	$\frac{139}{139}$	$\frac{74}{74}$	$\frac{76}{78}$	$\frac{67}{67}$	$\frac{72}{72}$	$\frac{51}{51}$
Flights 3, 4, 5, 8	1.00	1.00	1.00	0.977	1.00	1.00	1.00	1.00	0.974	1.00	1.00	1.00
P-3A Round Reliability	$\frac{137}{137}$	$\frac{100}{100}$	$\frac{98}{98}$	$\frac{121}{127}$	$\frac{192}{199}$	$\frac{293}{316}$	$\frac{317}{336}$	$\frac{226}{237}$	$\frac{123}{128}$	$\frac{90}{91}$	$\frac{72}{73}$	$\frac{60}{60}$
Flights 3, 4, 5, 8	1.00	1.00	1.00	0.953	0.965	0.927	0.943	0.954	0.961	0.989	1.00	1.00
P-3A TAU-1 Reliability	$\frac{90}{90}$	$\frac{54}{54}$	$\frac{49}{49}$	$\frac{36}{36}$	$\frac{35}{35}$	$\frac{30}{30}$	$\frac{48}{48}$	$\frac{28}{28}$	$\frac{32}{32}$	$\frac{39}{40}$	$\frac{36}{36}$	$\frac{36}{36}$
Flights 3, 4, 5, 8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.975	1.00	1.00
P-3A TAU-2 Reliability	$\frac{23}{23}$	$\frac{22}{22}$	$\frac{28}{29}$	$\frac{32}{34}$	$\frac{32}{32}$	$\frac{22}{22}$	$\frac{38}{38}$	$\frac{26}{26}$	$\frac{27}{28}$	$\frac{24}{24}$	$\frac{19}{20}$	$\frac{12}{12}$
Flights 3, 4, 5, 8	1.00	1.00	0.966	0.941	1.00	1.00	1.00	1.00	0.964	1.00	0.950	1.00

aircraft. Similarly, table XVI shows the various reliabilities established aboard the NC-117. Table XVII shows the combined reliabilities of the NC-117 and P-3A as a function of encounter angle. In general, the communication reliability aboard the P-3A was slightly better than that obtained aboard the NC-117.

The overall reliabilities without regard to encounter angle for the NC-117, P-3A, and the combination of the two are shown in table XVIII. The total of 1766 required pilot display indications were the result of 93 collision encounters, including 26 which involved three aircraft. The overall display reliability was 99.4 percent for encounters which were part of the daisy flight patterns. The overall round reliability based on 3238 target tracks which should have occurred during the above encounters was 96.0 percent.

As described earlier, additional head-on and tail-chase encounters were flown in order to obtain information regarding other aspects of the equipment operation. These encounters also provided data on communication reliability. The results of the additional encounters, when combined with the results of the daisy encounters, are also shown in Table XVIII.

The display reliability for head-on encounters, based on over 400 required displays, was 100 percent. The round reliability during the head-on encounters was also 100 percent. The lowest combined display reliability for a given encounter angle was 97.5 percent which occurred during the 90-degree encounters. The poorest round reliability for a given encounter angle was 92.7 percent which occurred during the tail chase encounters. However, the tail chase display reliability was 100 percent since the tracking failures occurred before the target aircraft became threats.

The reliability figures contained in table XVIII were the result of 111 collision encounters, all of which were conducted with an altitude separation of less than 600 feet (183 m). In addition, all tests were conducted in a simulated air traffic environment in excess of Honeywell predictions for the Los Angeles Basin in 1982.

ALTITUDE ZONE DISCRIMINATION

The AVOID II CAS classifies the altitude threat status of intruding aircraft on the basis of the replies that it receives in response to altitude coded interrogations. Interrogations are sequentially biased in order to determine occupancy of the various threat status bands. These altitude threat zones are shown in figure 17. Target aircraft can be classified because all aircraft respond only to interrogations of bands which include their altitude. The pattern of altitude band interrogations is shown in figure 18. The logical equations used in evaluating the responses to the interrogations are presented in figure 23.

It is necessary that a collision avoidance equipment be capable of distinguishing the various altitude threat zone boundaries both accurately and consistently. Poor resolution of either the ±600-foot (±183 m) or ±400-foot (±122 m) relative altitude boundaries would result in an unstable situation in which the pilot's display would alternate between commands (DIVE or CLIMB) and advisories (LIMIT VERTICAL SPEED DOWN or UP respectively).

TABLE XVI. COMMUNICATION RELIABILITY AS A FUNCTION OF ENCOUNTER ANGLE ABOARD THE NC-117

Encounter Angle (deg)	180	150	120	90	60	30	0	-30	-60	-90	-120	-150
NC-117 Display Reliability	95/95	59/59	63/65	70/72	61/63	41/41	95/95	48/48	50/50	49/50	46/46	41/41
Flights 4, 5, 8	1.00	1.00	0.969	0.972	0.968	1.00	1.00	1.00	1.00	0.980	1.00	1.00
NC-117 Round Reliability	98/98	59/60	67/67	86/87	131/135	213/227	232/256	167/172	82/87	56/58	48/48	41/41
Flights 4, 5, 8	1.00	0.983	1.00	0.989	0.970	0.938	0.906	0.971	0.943	0.966	1.00	1.00
NC-117 TAU-1 Reliability	61/61	33/34	31/32	34/35	29/31	22/22	37/37	20/20	22/22	28/28	25/25	26/26
Flights 4, 5, 8	1.00	1.00	0.969	0.971	0.935	1.00	1.00	1.00	1.00	1.00	1.00	1.00
NC-117 TAU-2 Coalt. Reliability	20/20	12/12	18/19	25/25	22/23	11/11	27/27	19/19	23/23	14/15	13/13	9/9
Flights 4, 5, 8	1.00	1.00	0.947	1.00	0.957	1.00	1.00	1.00	1.00	0.933	1.00	1.00

TABLE XVII. COMBINED NC-117 AND P-3A RELIABILITIES AS A FUNCTION OF ENCOUNTER ANGLE

Encounter Angle (deg)	180	150	120	90	60	30	0	-30	-60	-90	-120	-150
Combined NC-117 &P-3A Display	$\frac{227}{227}$	$\frac{159}{159}$	$\frac{156}{158}$	$\frac{156}{160}$	$\frac{144}{146}$	$\frac{105}{105}$	$\frac{234}{234}$	$\frac{122}{122}$	$\frac{126}{128}$	$\frac{116}{117}$	$\frac{118}{118}$	$\frac{92}{92}$
Reliability	1.00	1.00	0.987	0.975	0.986	1.00	1.00	1.00	0.984	0.991	1.00	1.00
Combined NC-117 & P-3A Round	$\frac{235}{235}$	$\frac{159}{160}$	$\frac{165}{165}$	$\frac{207}{214}$	$\frac{323}{334}$	$\frac{506}{543}$	$\frac{579}{592}$	$\frac{393}{409}$	$\frac{205}{215}$	$\frac{146}{149}$	$\frac{120}{121}$	$\frac{101}{101}$
Reliability	1.00	0.994	1.00	0.967	0.967	0.932	0.927	0.961	0.953	0.980	0.992	1.00
Combined NC-117 & P-3A TAU-1	$\frac{151}{151}$	$\frac{87}{88}$	$\frac{80}{81}$	$\frac{70}{71}$	$\frac{64}{66}$	$\frac{52}{52}$	$\frac{85}{85}$	$\frac{48}{48}$	$\frac{54}{54}$	$\frac{67}{68}$	$\frac{61}{61}$	$\frac{62}{62}$
Reliability	1.00	0.989	0.988	0.986	0.970	1.00	1.00	1.00	1.00	0.985	1.00	1.00
Combined NC-117 & P-3A TAU-2	$\frac{43}{43}$	$\frac{34}{34}$	$\frac{46}{48}$	$\frac{57}{59}$	$\frac{54}{55}$	$\frac{33}{33}$	$\frac{65}{65}$	$\frac{45}{45}$	$\frac{50}{51}$	$\frac{38}{39}$	$\frac{32}{33}$	$\frac{21}{21}$
Reliability	1.00	1.00	0.958	0.966	0.982	1.00	1.00	1.00	0.980	0.974	0.970	1.00

TABLE XVIII. SUMMARY AVOID II COMMUNICATION RELIABILITIES

	Daisy Flight Test Encounters		
	NC-117	P-3A	Combined
Display Reliability	$\frac{718}{725}$ = 0.990	$\frac{1037}{1041}$ = 0.996	$\frac{1755}{1766}$ = 0.994
Round Reliability	$\frac{1280}{1336}$ = 0.958	$\frac{1829}{1902}$ = 0.962	$\frac{3109}{3238}$ = 0.960
TAU-1 Reliability	$\frac{368}{373}$ = 0.987	$\frac{513}{514}$ = 0.998	$\frac{881}{887}$ = 0.993
TAU-2 Reliability	$\frac{213}{216}$ = 0.986	$\frac{305}{310}$ = 0.984	$\frac{518}{526}$ = 0.985

	Overall Flight Encounters
Display Reliability	$\frac{1911}{1922}$ = 0.994
Round Reliability	$\frac{3645}{3774}$ = 0.966
TAU-1 Reliability	$\frac{960}{968}$ = 0.992
TAU-2 Reliability	$\frac{536}{544}$ = 0.985
Non-Coaltitude TAU-2 Reliability	$\frac{435}{437}$ = 0.995

INTRUDER EQUATION

$$
\begin{aligned}
(I) = H_i[&G_{i+1} + G_i + G_{i-1}] \cdot [F_{i+1} + F_i + F_{i-1}] \cdot \\
&[E_{i+1} + E_i + E_{i-1}] \cdot [D_{i+1} + D_i + D_{i-1}] \cdot \\
&[C_{i+1} + C_i + C_{i-1}] \cdot [B_{i+1} + B_i + B_{i-1}] \cdot A_i + \\
H_i[&G_{i+2} \cdot \overline{\phi}_1 \cdot \overline{\phi}_6 \cdot \overline{\phi}_7 + G_{i+1} + G_i] \cdot \\
&[F_{i+2} + F_{i+1} + F_i] \cdot [E_{i+2} + E_{i+1} + E_i] \cdot \\
&[D_{i+2} + D_{i+1} + D_i] \cdot [C_{i+2} + C_{i+1} + C_i] \cdot \\
&[B_{i+2} \cdot \overline{\phi}_1 \cdot \overline{\phi}_6 \cdot \overline{\phi}_7 + B_{i+1} + B_i] \cdot A_i
\end{aligned}
$$

CORRELATION EQUATIONS

$$
\begin{aligned}
H(6) = H_i \cdot [H_{i+1} + H_i + H_{i-1}]^6 \cdot \\
&[G_{i+2} \cdot [G_{i+3} + G_{i+2} + G_i]^6 + G_{i+1} \cdot [G_{i+2} + G_{i+1} + G_i]^6 \\
&+ G_i \cdot [G_{i+1} + G_i + G_{i-1}]^6 + G_{i-1}[G_i + G_{i-1} + G_{i-2}]^6]
\end{aligned}
$$

$$
\begin{aligned}
H(4) = H_i \cdot [H_{i+1} + H_i + H_{i-1}]^4 \cdot \\
&[G_{i+2} [G_{i+3} + G_{i+2} + G_i]^4 + G_{i+1}[G_{i+2} + G_{i+1} + G_i]^4 \\
&+ G_i[G_{i+1} + G_i + G_{i-1}]^4 + G_{i-1}[G_i + G_{i-1} + G_{i-2}]^4
\end{aligned}
$$

$$
\begin{aligned}
H(0) = H_i[H_{i+1} + H_i + H_{i-1}]^o \\
&[G_{i+2}[G_{i+3} + G_{i+2} + G_{i+1}]^o + G_{i+1}[G_{i+2} + G_{i+1} + G_i]^o \\
&+ G_i[G_{i+1} + G_i + G_{i-1}]^o + G_{i-1}[G_i + G_{i-1} + G_{i-2}]^o
\end{aligned}
$$

Figure 23. AVOID II Altitude Threat Equations.

In order to establish the ability of the AVOID II equipment to distinguish relative altitude to within 100 feet (30.5 m), encounters with fixed altitude separations were flown. The altitude separations were chosen such that they would correspond as closely as possible to the boundaries of the altitude threat zones. These altitude separations were 1200 (366 m), 700 (213 m), 600 (183 m), 500 (152 m), and 400 feet (122 m). Encounters were then repeatedly flown within 100 feet (30.5 m) of and on both sides of each altitude threat boundary.

A total of 25 encounters during three flights were flown resulting in 1187 sequences during which only five incorrect altitude threat evaluations were recorded. In each case the incorrect altitude evaluation was the result of the unsuccessful receipt of replies to branch altitude interrogations (I (0), I (+4), or I (-4)). In no case was the pilot's display affected by these errors. The altitude threat zone tests were conducted in the presence of the simulated air traffic environment predicted for the Los Angeles Basin in 1982, and they established a reliability of 99.6 percent for the AVOID II altitude discrimination.

Significantly, the erroneous identification of altitude threat status as being more serious than the actual situation occurred only during three aircraft encounters, and this was the direct result of the aircraft being in a co-range situation. Again, the incorrect threat status appeared in the intermediate threat logic and never affected the pilot's display. A computer printout containing such a co-range situation is shown in figure 24.

During the three aircraft flight test, co-range situations occurred on numerous occasions and the AVOID II equipment was able to resolve the two intruders which were co-range within 100 to 200 feet (30.5 to 60.9 metres). In determining AVOID II co-range resolution capability, laboratory tests were conducted utilizing two separate traffic simulators to generate targets at the same altitude with respect to the AVOID II under test. The resolution was found to be between 100 (30.5 m) and 200 feet (60.9 m). Similar tests were conducted with the target generated by one traffic simulator above the test unit's simulated altitude and the second traffic simulator target below. Incorrect altitude threat evaluations occurred only when the range rates of the two targets were within 30 knots (15.4 m/s). That is, the two targets had to be separated by a distance less than the altitude response acceptance window (150 feet) (45.7 m) during the interrogation sequence. Furthermore, the pilot's display was only affected when the relative range rates of the two targets were within 15 knots (7.7 m/s). In order for the pilot's display to be affected during flight, an aircraft must be in a situation with a threatening aircraft above and another below, with the two threatening aircraft at ranges which are within 200 feet (60.9 metres) of each other, and with the aircraft closing at range rates which are within 15 knots (7.7 m/s) of each other. Such a situation has an extremely low probability of occurrence.

FLIGHT NO. 8 ENCOUNTER NO. 7 DATE 8 1

TIME HR MIN SEC	DISPLAY	TARGET NO. 1 RANGE	RATE	TAU	THR 1	TARGET NO. 2 RANGE	RATE	TAU	THR 2	ALT	RPLS	IXMT	IRCD				
12 17 13.3		.000	0	0		.000	0	0		9.7	42.4	4	1627				
12 17 19.1		.000	0	0		.000	0	0		9.7	41.9	4	1611				
12 17 22.9		.000	0	0		.000	0	0		9.7	42.1	3	1622				
12 17 25.7		.000	0	0		.000	0	0		9.7	42.3	3	1637				
12 17 31.4		.000	0	0		.000	0	0		9.7	42.2	3	1622				
12 17 34.2		3.884	266	52		.000	0	0		9.7	42.5	17	1648				
12 17 38.0		3.621	268	50		.000	0	0		9.7	42.5	19	1637				
12 17 41.7		3.533	357	34	13A	3.357	265	45		9.7	42.7	24	1634	P5			
12 17 45.4	500A	3.176	357	31	13A	3.394	272	40	C82	9.7	42.4	25	1654	P5			T23
12 17 49.3	500A 500B	2.814	361	29	CA1	2.793	284	35	C82	9.7	42.0	24	1595		T1A		T23
12 17 53.1	500A 500B	2.436	355	24	13A	2.519	272	33	C82	9.7	42.2	23	1621	P5			T23
12 17 55.9	500A 500B	2.090	349	21	13A	2.255	265	30	C81	9.7	42.5	23	1627	P5		T1B	T23
12 18 .7	500ACLIMB	1.724	337	19	13A	1.975	272	26	C81	9.7	42.4	23	1649	P5		T1B	
12 18 4.4	500ACLIMB	1.415	319	15	13A	1.695	272	22	C81	9.7	41.8	23	1587	P5		T1B	
12 18 8.3	500ACLIMB	1.119	284	14	13A	1.415	272	18	C81	9.7	42.0	24	1632	P5		T1B	
12 18 12.6	500ACLIMB	.859	225	14	13A	1.152	265	15	C81	9.7	42.4	23	1644	P5		T1B	
12 18 16.0	500ACLIMB	.774	106	25	13A	.872	265	11	C81	9.7	42.4	23	1665	P5		T1B	
12 18 19.9	500ACLIMB	.823	-53	99	13A	.592	260	8	C81	9.7	42.4	23	1652	P5		T1B	
12 18 23.6	500ACLIMB	.352	236	5	C81	.000	0	0		9.7	42.4	20	1682			T1B	
12 18 27.4	CLIMB	.000	0	0		.000	0	0		9.7	42.2	18	1655				
12 18 31.3		.000	0	0		.000	0	0		9.7	42.1	12	1535				
12 18 35.1		.000	0	0		.000	0	0		9.7	42.1	3	1556				
12 18 39.0		.000	0	0		.000	0	0		9.7	42.2	3	1620				
12 18 42.7		.000	0	0		.000	0	0		9.7	42.0	3	1552				
12 18 46.5		.000	0	0		.000	0	0		9.7	42.4	3	1636				
12 18 50.3		.000	0	0		.000	0	0		9.7	42.2	7	1613				
12 18 54.1		.000	0	0		.000	0	0		9.7	42.1	4	1547				
12 18 57.9		.000	0	0		.000	0	0		9.7	42.4	4	1631				
12 19 1.7		.000	0	0		.000	0	0		9.7	42.5	4	1659				
12 19 5.4		.000	0	0		.000	0	0		9.7	42.2	3	1633				
12 19 9.1		.000	0	0		.000	0	0		9.7	42.2	3	1642				
12 19 12.9		.000	0	0		.000	0	0		9.7	42.2	3	1635				
12 19 16.7		.000	0	0		.000	0	0		9.7	42.6	3	1650				
12 19 20.5		.000	0	0		.000	0	0		9.7	42.1	3	1688				
12 19 24.3		.000	0	0		.000	0	0		9.7	42.1	3	1657				
12 19 28.1		.000	0	0		.000	0	0		9.7	42.2	3	1637				
12 19 31.9		.000	0	0		.000	0	0		9.7	41.9	3	1599				
12 19 35.5		.000	0	0		.000	0	0		9.7	42.1	3	1637				
12 19 39.4		.000	0	0		.000	0	0		9.7	42.5	3	1552				
12 19 43.1		.000	0	0		.000	0	0		9.7	42.3	4	1533				
12 19 46.7		.000	0	0		.000	0	0		9.7	42.6	3	1649				
12 19 50.5		.000	0	0		.000	0	0		9.7	42.5	3	1561				
12 19 54.1		.000	0	0		.000	0	0		9.7	42.3	3	1627				
12 19 57.9		.000	0	0		.000	0	0		9.7	41.8	3	1625				
12 20 1.7		.000	0	0		.000	0	0		9.7	42.0	3	1637				

Figure 24. Computer Printout of Data Recorded Aboard the P-3A, Flight 8, Encounter 7.

AVOID I - AVOID II COMPATIBILITY

INTRODUCTION

The AVOID I and AVOID II represent the maximum and minimum equipments comprising the AVOID collision avoidance system. The AVOID I is designed for military and air carrier aircraft which fly the civil air lanes. As such, the AVOID I incorporates the highest levels of protection possible. The AVOID II is a smaller, less costly version designed for lower performance military and civilian aircraft. Table XIX shows the major differences between the AVOID I and AVOID II system parameters. The parameters which have the most significant effect on equipment compatibility are the power budgets, the intruder tracking ranges, and the different threat zones associated with each equipment.

The AVOID II is not designed for operation above an altitude of 10,000 feet (3.05 km). The AVOID I, which is capable of operating in all altitude regimes, adjusts its level of operation to that of an AVOID II when below 10,000 feet (3.05 km). That is, below 10,000 feet (3.05 km), the AVOID I processes targets with closure rates less than 540 knots (278 m/s). Apparently, range rate should not affect the compatibility of the two equipment types. However, a maximum identifiable closure rate of 540 knots (278 m/s) does not provide a reasonable safety margin. A 540-knot (278 m/s) maximum will provide adequate protection for encounters involving an AVOID I equipped aircraft and a low performance AVOID II equipped aircraft, but encounters between two AVOID I equipped aircraft can exceed 540 knots (278 m/s). This maximum value can be exceeded during near head-on encounters between two aircraft travelling at high but allowable air speeds below 10,000 feet (3.05 km). The regulation limit for aircraft below 10,000 feet (3.05 km) is 250 knots indicated air speed or 275 knots (141 m/s) true air speed. True air speed differs from indicated air speed as a function of altitude and temperature. The AVOID system measures true air speed. Thus, two aircraft travelling at indicated rates of 250 knots (129 m/s) could be closing at a true rate in excess of 540 knots (278 m/s).(ie. 550) (283 m/s) and not be tracked by the AVOID CAS equipment. Another situation which might result in marginal protection is that which involves an encounter between an aircraft just above the 10,000 foot (3.05 km) boundary (actually 9600 feet (2.93 km) in the AVOID system) and one just below the boundary. An AVOID II aircraft in such a situation would not track the aircraft above 10,000 feet (3.05 km) until its air speed reduced enough to result in a closure rate less than 540 knots (278 m/s).

COMMUNICATION RANGE (POWER BUDGET)

The AVOID II CAS equipment transmits pulses at a level in excess of 54 dbm and operates with a receiver sensitivity which is better than -68 dbm. The communication loop sensitivity between AVOID II equipments can be considered to be greater than 122 dbm. This level represents a theoretical average communication range of 8.4 nautical miles (15.6 km). As designed, the AVOID I CAS transmits pulses at a level of 58 dbm below 9600 feet (2.93 km) (63 dbm above 9600 ft (2.93 km), and operates with a receiver sensitivity of -71 dbm. Thus, the

TABLE XIX. AVOID SYSTEM PARAMETERS

Altitude Coverage

AVOID I	± 1200 ft.	Level Flight
	± 2100 ft.	Vertical Rate >± 500 fpm
	± 3200 ft.	Vertical Rate >± 1000 fpm
AVOID II	± 1200 ft.	No Provision for Vertical Rate

Range (Intruder Tracking)

AVOID I	~ 15 nmi	≥ 9600 feet altitude
	~ 7.5 nmi	< 9600 feet altitude
AVOID II	4.2 nmi	

Range Rate (Maximum)

AVOID I	1200 knots	≥ 9600 feet altitude
	540 knots	< 9600 feet altitude
AVOID II	540 knots	

Communication Link

	Transmitter Power	Receiver Sensitivity
AVOID I	58 dbm	-71 dbm < 9600 feet altitude
	62 dbm	-71 dbm ≥ 9600 feet altitude
AVOID II	54 dbm	-68 dbm

communication loop sensitivity between AVOID I equipments below 9600 feet (2.93 km) can be considered to be 129 dbm. This level represents an average communication range which is more than twice the link range of the AVOID II aircraft. Since the AVOID I and AVOID II transmit at different power levels and operate with different receiver sensitivities, two different link strengths result. However, the communication loop sensitivity is equivalent to the weakest combination of receiver and transmitter strengths. Since the AVOID I transmits pulses at 58 dbm and the AVOID II has a receiver sensitivity of -68 dbm, the various communication path losses can amount to 126 dbm. When the AVOID II generates its reply at 54 dbm with the AVOID I receiver sensitivity of -71 dbm, the total path losses can only be 125 dbm. This means that the theoretical average communication range between aircraft equipped with different AVOID systems should be better than 11.5 nautical miles.

The actual transmitter power and receiver sensitivity of the AVOID I and AVOID II were measured during laboratory tests. The AVOID I used during testing had a transmitter power of 57.5 dbm for altitudes above 9600 feet (2.93 km) and 53.5 dbm for altitudes below 9600 feet (2.93 km). The original receiver sensitivity measured during the AVOID I flight tests was -74.5 dbm, but similar measurements made during the AVOID II flight tests showed that the particular AVOID I (SN/1) flown during AVOID II flight tests had a sensitivity of -71 dbm. All encounters involving the AVOID I were flown at an altitude above 9600 feet (2.93 km); consequently, the proper power budget was achieved during the flight tests. At the same time, flying the test encounters above 9600 feet (2.93 km) had no effect on the operation of the AVOID II since its transmitter power and altitude coverage zones are the same above and below 9600 feet (2.93 km) (the AVOID II is designed for operation below 9600 feet (2.93 km) only).

The actual communication range achieved between an AVOID I and an AVOID II equipped aircraft could only be measured aboard the AVOID I equipped aircraft because of the limited tracking range of the AVOID II. During all flight tests, the RA-3B was equipped with the AVOID I. The AVOID I equipment used during the flight testing of the AVOID II did not incorporate the improved interrogation sequence which will be utilized in future AVOID I equipments.

Figure 25 shows the communication range for the head-on (180 deg) encounters during flight 6. These encounters were flown with an altitude separation of 500 feet (152 m). The communication reliability level at different ranges during each encounter is included. The communication reliabilities indicated were determined by the number of successfully completed communication sequences as compared with the number of communication sequences which should have occurred between that point and the closest point of approach between the two aircraft. The lowest communication range and reliability which occurred was an 84 percent reliability at a range of 7 nautical miles during the first encounter. During succeeding head-on encounters, the communication reliability improved considerably with the result that the overall communication reliability for the head-on encounters was 97 percent at a range of 7.4 nautical miles. Figure 26 shows the average communication range and reliability as a function of encounter angle for flight 6. As the figure indicates, the communication reliabilities were still high at ranges in excess of 7 nautical miles (13 km) with the exception of the -30-degree encounter angle. This low point in communication range is greater than that required for the appropriate warning times at this encounter angle below 9600 feet (2.93 km).

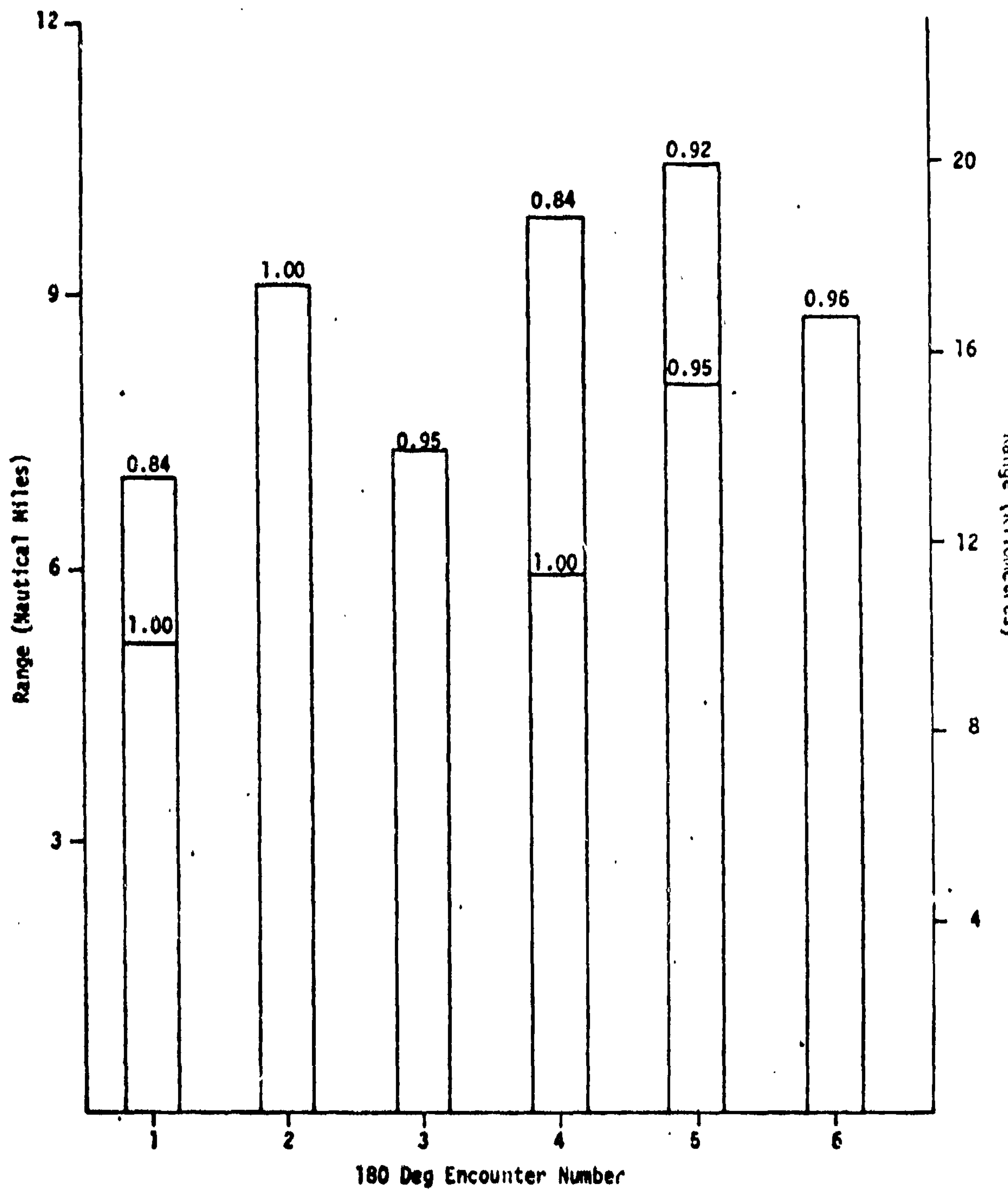


Figure 25. Communication Range and Reliability During Head-On Encounters, Flight 6.

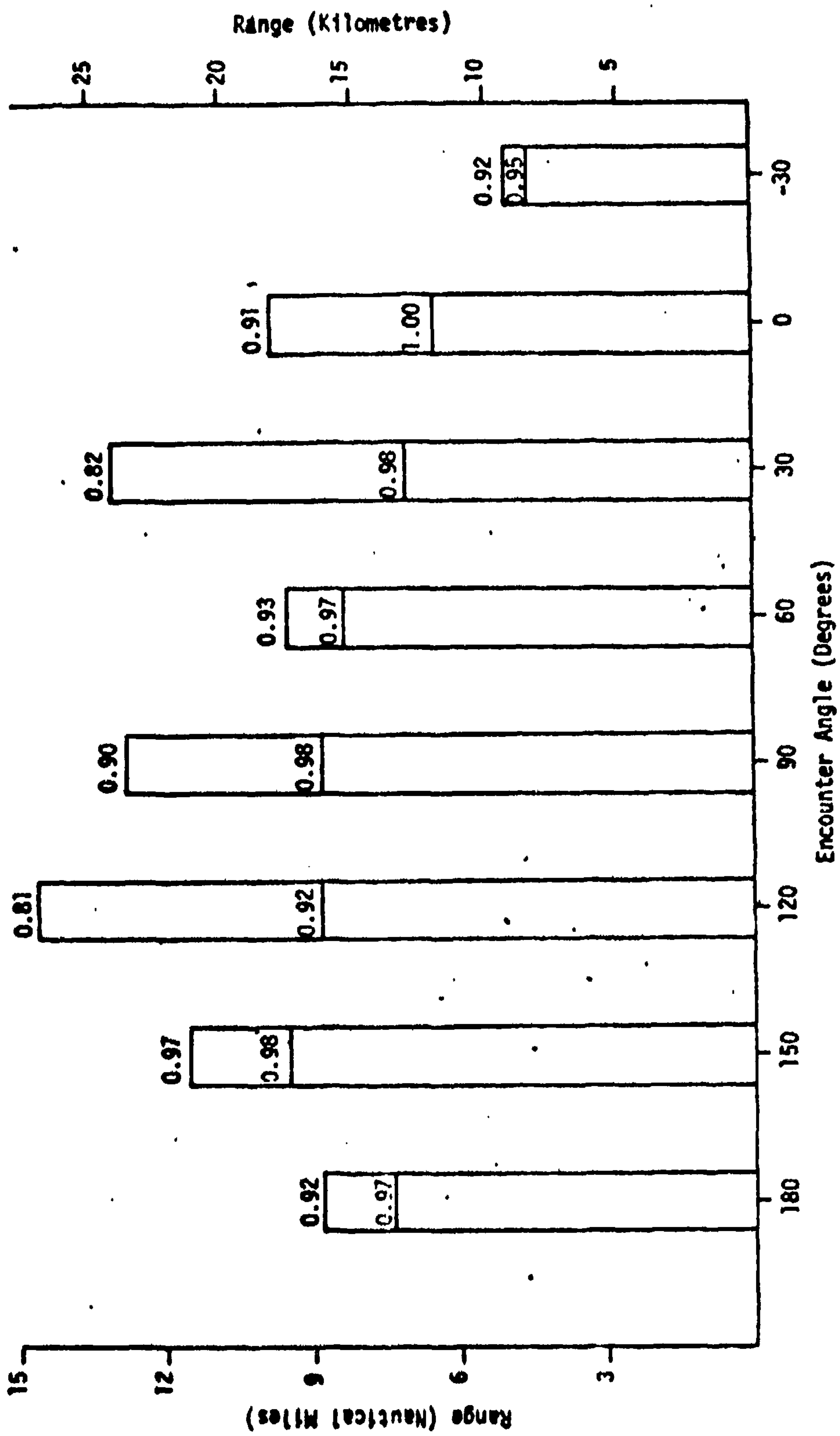


Figure 26. Average Communication Range and Reliability as a Function of Encounter Angle, Flight 6.

Figure 27 shows the average communication range and reliability as a function of encounter angle for flight 7. Flight 7 was similar in most aspects to flight 6, the major difference was that the P-3A rather than the NC-117 participated in the flight encounters. As a result, the closure rates of the encounters during flight 7 were higher than those of flight 6. As is indicated in figure 27, the communication reliability exceeded 85 percent at an average range of 9 nautical miles (16.7 km) for all encounter angles with the exception of the -30-degree encounter angle. For the -30-degree encounter angle, the communication range measurement was limited by the geometric restrictions of the flight test pattern.

Flight 8, which was conducted on August 1, 1975, consisted of encounters involving all three aircraft. The AVOID I equipped RA-3B flew a figure 8 pattern at an altitude of 10.5 thousand feet (3.20 km). The P-3A flew the daisy pattern at an altitude of 9.8 thousand feet (2.99 km). The NC-117 flew a figure 8 pattern at an altitude of 9.3 thousand feet (2.83 km) which resulted in repeated head-on encounters with the RA-3B during the entire flight. Figure 28 contains a printout of data recorded aboard the P-3A during the 3 aircraft encounters. Figures 29 and 30 show the data recorded aboard the NC-117 and the P-3A during the same encounter.

Flight 8 commenced with the RA-3B and P-3A flying the same course which resulted in head-on encounters with the NC-117. Due to the air speeds associated with the various aircraft and the geometry of the flight pattern, the RA-3B would track the P-3A, which was closer in range at the start of the flight pattern, until the NC-117 with a higher closure rate became the closer of the two target aircraft. However, during encounter angles between the RA-3B and the P-3A which were greater than 90 degrees, the initial range between the RA-3B and the P-3A was greater than that between the RA-3B and the NC-117. Consequently, during flight 8 the communication range between the RA-3B and P-3A could only be measured for encounter angles of 90 degrees or less. The average communication range and reliability as a function of encounter angle for flight 8 between the RA-3B and the P-3A are plotted in figure 31. Similarly, the communication range between the RA-3B and the NC-117 was masked during certain encounter angles by the presence of the P-3A. The average communication range and reliability for the head-on encounters between the RA-3B and the NC-117 are shown in figure 32. For purposes of comparison, the results of the head-on encounters which occurred during flight 6 are also shown. As the plotted data indicates, the communication range achieved during flight 8 was about twice the range obtained during flight 6. The significant difference between the two flights was the altitude separation. The relative altitude of the aircraft was 500 feet (152 m) during flight 6 and 1200 feet (366 m) during flight 8. This difference appears to substantiate the possible existence of large gain variations in the antenna patterns. Data accumulated during both the AVOID I and AVOID II flight tests failed to conclusively prove or disprove the existence of significant nulls in the antenna patterns of the aircraft utilized.

The flights between AVOID I and AVOID II equipped aircraft resulted in communication reliabilities which exceeded 90 percent at a range greater than 7 miles (13 km) for encounter angles greater than 90 degrees. The communication range required by the AVOID system to generate a 40-second warning with a closure rate between aircraft of 550 knots (283 m/s) is 7.24 nautical miles (13.4 kilo-

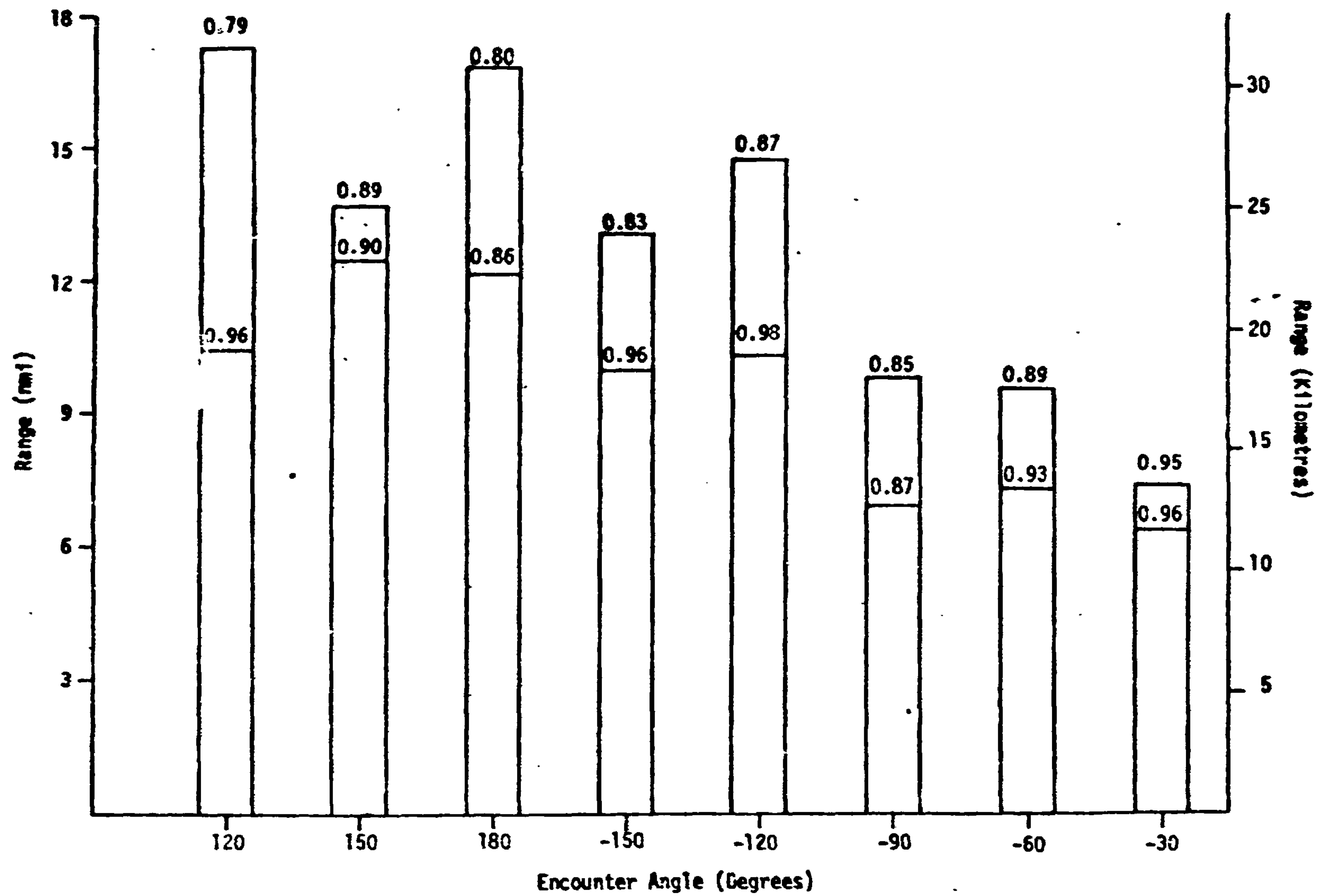


Figure 27. Average Communication Range and Reliability as a Function of Encounter Angle, Flight 7.

FLIGHT NO. 8 ENCOUNTER NO. 5 DATE 8 1

TIME				TARGET NO. 1				TARGET NO. 2										
HR	MIN	SEC	DISPLAY	RANGE	RATE	TAU	THR 1	RANGE	RATE	TAU	THR 2	ALT	RPLS	IXMT	IRCD			
12	8	43.1		.000	0	0		.000	0	0		9.7	41.9	3	1614			
12	8	53.0		.000	0	0		.000	0	0		9.7	42.3	3	1665			
12	8	55.7		.000	0	0		.000	0	0		9.7	41.8	3	1614			
12	9	.6		.000	0	0		.000	0	0		9.7	42.1	3	1643			
12	9	4.2		.000	0	0		.000	0	0		9.7	42.0	3	1645			
12	9	8.0		.000	0	0		.000	0	0		9.7	41.9	3	1647			
12	9	11.6		.000	0	0		.000	0	0		9.7	42.1	4	1637			
12	9	15.4		.000	0	0		.000	0	0		9.7	42.0	3	1624			
12	9	19.2		.000	0	0		.000	0	0		9.7	42.2	3	1654			
12	9	22.9		.000	0	0		.000	0	0		9.7	41.8	3	1611			
12	9	26.7		.000	0	0		.000	0	0		9.7	42.0	3	1653			
12	9	30.5		.000	0	0		.000	0	0		9.7	42.0	3	1623			
12	9	34.2		.000	0	0		.000	0	0		9.7	42.1	3	1606			
12	9	38.0		.000	0	0		.000	0	0		9.7	42.4	4	1535			
12	9	41.7		.000	0	0		.000	0	0		9.7	42.2	3	1625			
12	9	45.4		.000	0	0		.000	0	0		9.7	42.4	4	1633			
12	9	49.0		.000	0	0		.000	0	0		9.7	42.0	3	1633			
12	9	52.8		.000	0	0		.000	0	0		9.7	41.9	3	1622			
12	9	56.6		.000	0	0		.000	0	0		9.7	42.0	3	1619			
12	10	.4		.000	0	0		.000	0	0		9.7	42.2	3	1659			
12	10	4.3		3.901	284	49		.000	0	0		9.7	42.3	11	1648			
12	10	8.1		3.694	284	45		.000	0	0		9.7	42.0	12	1639			
12	10	11.9		3.341	272	44	13A	.000	0	0		9.7	42.1	11	1632	P5		
12	10	15.6	503A	3.078	256	41	13A	3.884	319	43	C92	9.7	42.3	23	1622	P5	TBT23	+
12	10	19.5	508A 5008	2.814	243	40	13A	3.555	319	40	C92	9.7	42.2	27	1619	P5	TBT23	+
12	10	27.2	503A 5009	2.584	236	39	13A	3.226	337	34	CB2	9.7	42.2	27	1640	P5	TBT23	+
12	10	26.9	509A 5008	2.337	236	35	13A	2.963	343	33	CB2	9.7	41.8	27	1633	P5	TBT23	+
12	10	31.8	503A 5009	2.093	242	31	13A	2.535	331	27	C91	9.7	42.2	27	1625	P5	T18T8	+
12	10	34.5	503ACLIMB	1.843	248	25	13A	2.222	325	24	CB1	9.7	42.3	27	1644	P5	T18T8	+
12	10	39.4	503ACLIMB	1.563	254	22	13A	1.876	325	20	C91	9.7	42.3	23	1642	P5	T18TB	+
12	10	42.2	503ACLIMB	1.300	260	19	13A	1.563	314	17	C91	9.7	42.3	27	1632	P5	T18T8	+
12	10	45.9	503ACLIMB	1.037	260	14	13A	1.234	309	14	C91	9.7	42.4	27	1657	P5	T18T8	+
12	10	49.8	503ACLIMB	.826	231	12	13A	.955	279	12	CB1	9.7	42.3	27	1639	P5	T18T8	+
12	10	53.5	500ACLIMB	.625	171	13	13A	.591	249	10	C91	9.7	41.9	27	1627	P5	T18T8	+
12	10	57.4	500ACLIMB	.592	35	63	13A	.543	135	14	CB1	9.7	42.3	28	1634	P5	T18T8	+
12	11	1.3	500ACLIMB	.000	0	0		.000	0	0		9.7	42.5	27	1655			+
12	11	5.0		.000	0	0		.000	0	0		9.7	42.6	9	1652			
12	11	8.9		.000	0	0		.000	0	0		9.7	42.2	7	1640			
12	11	12.6		.000	0	0		.000	0	0		9.7	42.3	3	1641			
12	11	16.3		.000	0	0		.000	0	0		9.7	42.3	4	1648			
12	11	20.0		.000	0	0		.000	0	0		9.7	42.3	3	1643			
12	11	23.8		.000	0	0		.000	0	0		9.7	42.3	4	1650			
12	11	27.6		.000	0	0		.000	0	0		9.7	42.3	3	1625			
12	11	31.4		.000	0	0		.000	0	0		9.7	42.1	3	1631			
12	11	35.2		.000	0	0		.000	0	0		9.7	42.4	4	1657			

Figure 28. Computer Printout of Data Recorded Aboard the P-3A During a Three Aircraft Encounter, Flight 8.

FLIGHT NO. 8 ENCOUNTER NO. 6 DATE 8 1

TIME				TARGET NO. 1				TARGET NO. 2									
HR	MIN	SEC	DISPLAY	RANGE	RATE	TAU	THR 1	RANGE	RATE	TAU	THR 2	ALT	RPLS	IXMT	IRCO		
2	8	55.7		.000	0	0		.000	0	0		9.3	39.5	3	1719		
2	8	59.3		.000	0	0		.000	0	0		9.3	40.8	7	1729		
2	9	3.0		.000	0	0		.000	0	0		9.3	40.1	3	1738		
2	9	6.7		.000	0	0		.000	0	0		9.3	39.5	3	1729		
2	9	10.3		.000	0	0		.000	0	0		9.3	39.4	3	1720		
2	9	14.0		.000	0	0		.000	0	0		9.3	39.3	3	1702		
2	9	17.7		.000	0	0		.000	0	0		9.3	39.7	3	1706		
2	9	21.6		.000	0	0		.000	0	0		9.3	39.5	4	1726		
2	9	25.4		.000	0	0		.000	0	0		9.3	39.4	3	1683		
2	9	29.1		.000	0	0		.000	0	0		9.3	39.6	3	1690		
2	9	32.8		.000	0	0		.000	0	0		9.3	39.4	3	1733		
2	9	36.6		.000	0	0		.000	0	0		9.3	39.8	3	1696		
2	9	40.2		.000	0	0		.000	0	0		9.3	39.8	3	1744		
2	9	43.9		.000	0	0		.000	0	0		9.3	39.7	3	1704		
2	9	47.7		.000	0	0		.000	0	0		9.3	39.7	3	1715		
2	9	51.4		.000	0	0		.000	0	0		9.3	39.5	3	1717		
2	9	55.0		.000	0	0		.000	0	0		9.3	39.7	3	1752		
2	9	58.8		.000	0	0		.000	0	0		9.3	39.5	3	1703		
2	10	2.6		.000	0	0		.000	0	0		9.3	39.5	3	1688		
2	10	6.3		.000	0	0		.000	0	0		9.3	39.4	3	1734		
2	10	10.1		.000	0	0		.000	0	0		9.3	39.9	3	1776		
2	10	13.7		.000	0	0		.000	0	0		9.3	39.7	3	1756		
2	10	17.3		3.785	308	44	CA2	.000	0	0		9.3	40.1	17	1760	T2A	
2	10	21.0	500A	3.456	314	39	CA2	.000	0	0		9.3	39.8	16	1762	T2A	
2	10	24.8	500A	3.127	325	34	CA2	.000	0	0		9.3	39.8	16	1750	P5T2A	
2	10	28.5	500A	2.798	331	30	CA2	.000	0	0		9.3	39.7	16	1702	P5T2A	
2	10	32.2	500A	2.469	337	26	CA1	.000	0	0		9.3	39.6	16	1705	P5	T1A
2	10	36.0	DIVE	2.024	462	15	13A	.000	0	0		9.3	39.5	17	1727	P5	T1A
2	10	39.8	DIVE	1.547	456	12	13A	.000	0	0		9.3	39.2	17	1688	P5	T1A
2	10	43.5	DIVE	1.086	450	8	13A	.000	0	0		9.3	39.2	17	1693	P5	T1A
2	10	47.3	DIVE	.642	438	5	13A	.000	0	0		9.3	39.2	16	1678	P5	T1A
2	10	50.8	DIVE	.905	278	11	CA1	.000	0	0		9.3	39.4	16	1718		T1A
2	10	54.6	DIVE	.658	231	10	CA1	.000	0	0		9.3	39.3	18	1717		T1A
2	10	58.4	DIVE	.543	124	15	CA1	.000	0	0		9.3	39.3	16	1738		T1A
2	11	2.0	DIVE	.000	0	0		.000	0	0		9.3	39.6	16	1722		
2	11	5.7		.000	0	0		.000	0	0		9.3	39.4	10	1701		
2	11	9.3		.000	0	0		.000	0	0		9.3	39.5	3	1713		
2	11	12.9		.000	0	0		.000	0	0		9.3	39.6	9	1734		
2	11	16.8		.000	0	0		.000	0	0		9.3	39.4	3	1676		
2	11	20.4		.000	0	0		.000	0	0		9.3	39.7	3	1738		
2	11	24.2		.000	0	0		.000	0	0		9.3	39.5	3	1706		
2	11	27.9		.000	0	0		.000	0	0		9.3	39.6	3	1711		
2	11	31.6		.000	0	0		.000	0	0		9.3	39.5	3	1730		
2	11	35.4		.000	0	0		.000	0	0		9.3	39.3	3	1700		
2	11	39.1		.000	0	0		.000	0	0		9.3	39.4	7	1734		

Figure 29. Computer Printout of Data Recorded Aboard the NC-117 During a Three Aircraft Encounter, Flight 8.

FLIGHT NO. 8 ENCOUNTER NO. 1 DATE 8 1

TIME HR	MIN	SEC	DISPLAY	TARGET NO. 1 RANGE	RATE	TAU	THR 1	TARGET NO. 2 RANGE	RATE	TAU	THR 2	ALT	RPLS	IXMT	IRCD			
12	9	7.5		7.635	254	90		12.919	456	90		10.5	5.8	30	80			0
12	9	13.7		7.439	242	90		.000	0	0		10.5	5.8	30	100			0
12	9	13.8		7.225	248	90		12.179	414	90		10.5	5.7	30	86			0
12	9	16.9		7.011	231	90		.000	0	0		10.5	5.9	30	100			0
12	9	20.0		6.830	207	90		11.405	432	90		10.5	6.1	30	111			0
12	9	23.1		6.633	231	90		.000	0	0		10.5	5.6	30	87			0
12	9	26.1		6.451	213	90		.000	0	0		10.5	5.6	30	82			0
12	9	29.2		.000	0	0		.000	0	0		10.5	6.2	30	119			0
12	9	32.3		9.908	456	78		9.908	456	78		10.5	5.4	30	80			0
12	9	35.5		9.546	420	81		.000	0	0		10.5	5.7	30	65			0
12	9	38.5		5.694	207	90		9.167	438	75		10.5	6.1	30	111			0
12	9	41.6		5.497	225	87		.000	0	0		10.5	5.6	30	89			0
12	9	44.7		8.394	438	68		8.394	456	66		10.5	6.1	30	103			0
12	9	47.8		5.118	219	84		.000	0	0		10.5	6.1	30	112			0
12	9	50.9		4.904	236	74		7.636	438	62		10.5	6.4	30	124			0
12	9	54.0		4.690	236	71	CB2	.000	0	0		10.5	6.0	30	105		T26M5	0
12	9	57.1	2308	4.477	254	63	CB2	6.879	432	57	138	10.5	5.4	30	97		T26M6	0
12	10	.2	2308	4.246	260	58	CB2	.000	0	0		10.5	5.8	30	91		T26M5	0
12	10	3.3	2308	4.016	272	53	CB2	5.122	432	50	138	10.5	6.3	30	124		T26M5	0
12	10	6.4	2308	3.785	256	51	CB2	.000	0	0		10.5	5.7	30	87		T26M5	0
12	10	9.5	2308	3.555	260	49	CB2	5.349	444	43	138	10.5	5.6	30	84		T26M5	0
12	10	12.6	2308	3.341	250	46	CB2	.000	0	0		10.5	5.8	30	99		T26M5	0
12	10	15.7	2308	3.111	248	45	CB2	4.592	444	37	138	10.5	6.0	30	112		T26M5	0
12	10	18.3	2308	2.913	242	43	CB2	.000	0	0		10.5	5.5	30	95		T26M5	0
12	10	21.8	2308	2.716	231	42	CB2	3.862	444	33	138	10.5	6.1	30	123		T26M5	0
12	10	24.9	2308	2.532	225	40	CB2	.000	0	0		10.5	5.7	30	130		T26M5	0
12	10	28.0	2308	2.304	225	36	CB2	3.028	450	24	138	10.5	6.1	30	128		T26M5	0
12	10	31.1	2308	2.107	235	32	CB2	.000	0	0		10.5	5.6	30	105		T26M5	0
12	10	34.2	CLIMB	1.893	242	28	CB1	2.255	456	17	138	10.5	5.3	30	71	T18	M5	0
12	10	37.3	CLIMB	1.695	236	25	CB1	.000	0	0		10.5	6.6	30	150	T18	M5	0
12	10	40.4	CLIMB	1.441	242	22	CB1	1.498	432	12	138	10.5	5.6	30	100	T18	M5M10	0
12	10	43.5	CLIMB	1.103	-38	9	138	.000	0	0		10.5	5.5	30	93	T18	M5M10	0
12	10	46.5	CLIMB	.741	-26	6	138	.741	414	6	CB1	10.5	5.9	30	125	T18	M5	0
12	10	49.7	CLIMB	.395	335	3	138	.000	0	0		10.5	6.1	30	127	T18	M5	0
12	10	53.2	CLIMB	.658	165	12	CB1	.000	0	0		10.5	7.2	30	137	T18		0
12	10	56.3	CLIMB	.592	94	22	CB1	.000	0	0		10.5	6.3	30	146	T18		0
12	10	59.4	CLIMB	.000	0	0		.000	0	0		10.5	6.3	30	114			2
12	11	2.4		.724	-142	99		.000	0	0		10.5	5.7	30	132			0
12	11	5.5		.905	-213	99		.000	0	0		10.5	6.7	30	140			0
12	11	9.3		.000	0	0		.000	0	0		10.5	5.9	30	91			0
12	11	12.1		.000	0	0		.000	0	0		10.5	6.5	30	114			0
12	11	15.2		.000	0	0		.000	0	0		10.5	6.6	30	119			0
12	11	18.3		.000	0	0		.000	0	0		10.5	6.6	30	111			0
12	11	21.4		.000	0	0		.000	0	0		10.5	6.0	30	88			0
12	11	24.5		.000	0	0		.000	0	0		10.5	6.5	30	121			0

Figure 30. Computer Printout of Data Recorded Aboard the RA-3B During a Three Aircraft Encounter, Flight 8.

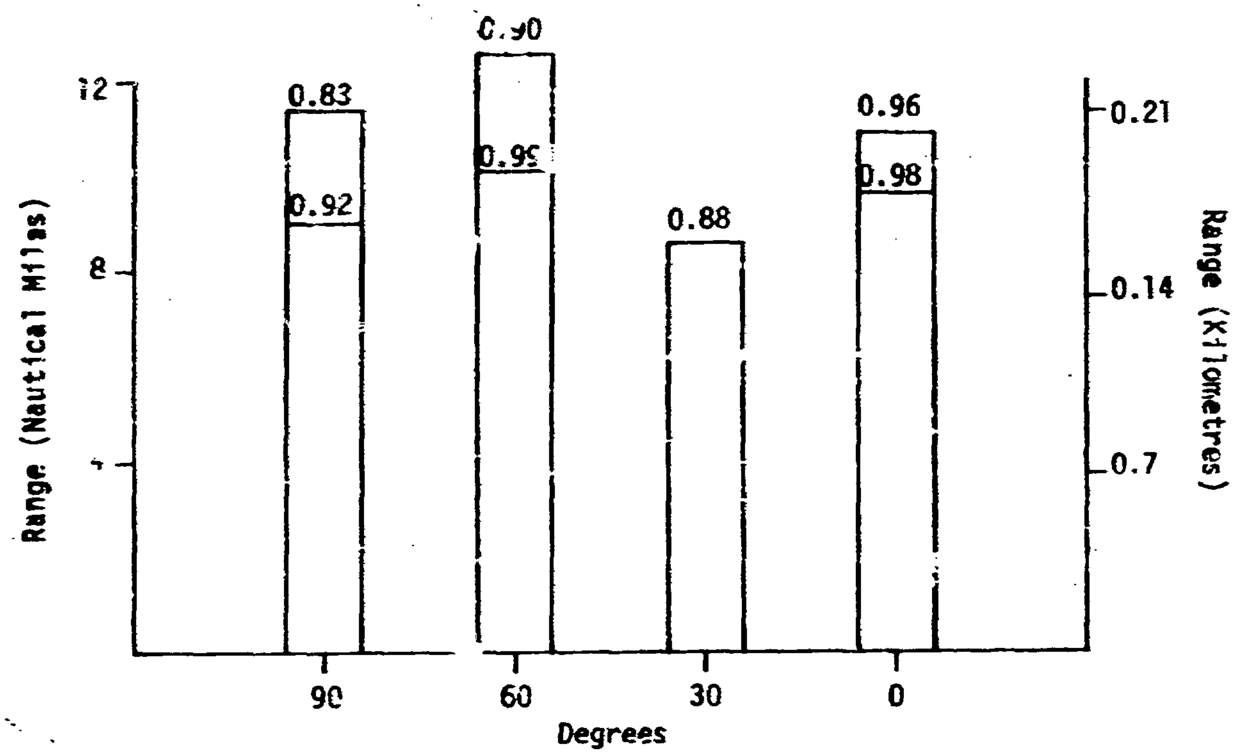


Figure 31. Average Communication Range and Reliability as a Function of Encounter Angle, Flight 8, RA-3B vs P-3A.

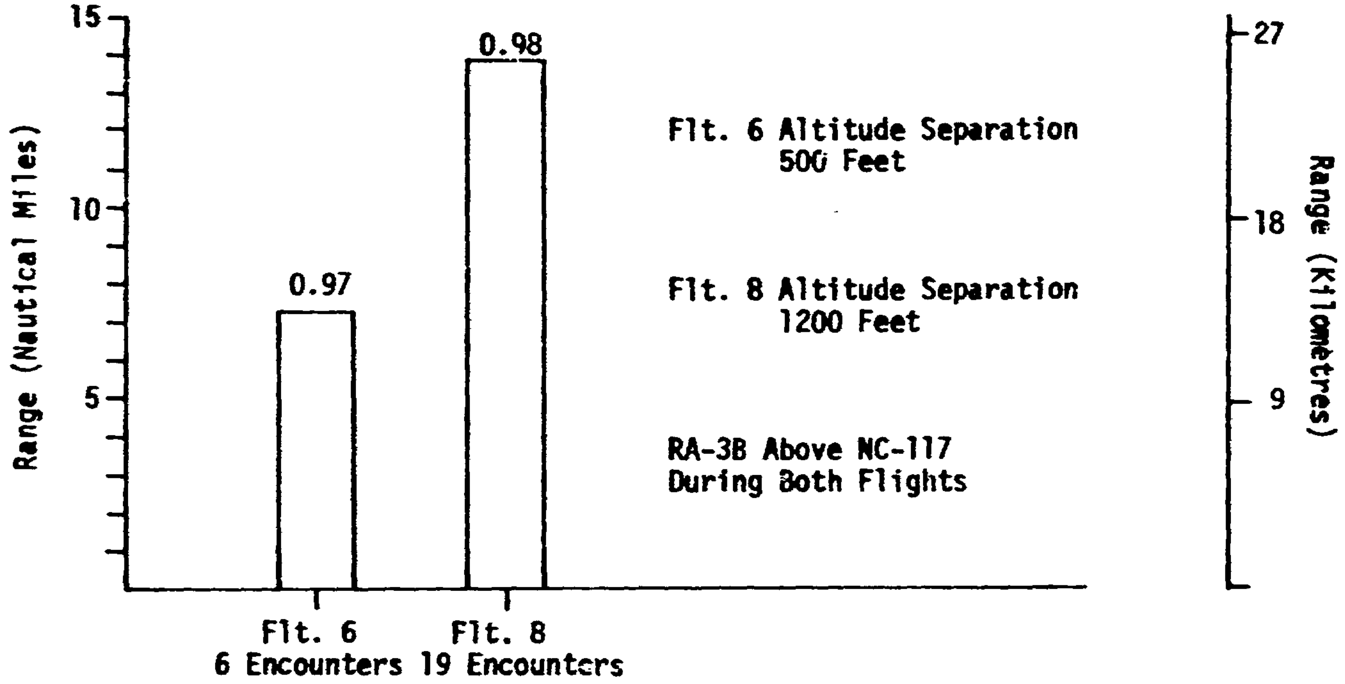


Figure 32. Average Communication Range and Reliability for Head-On Encounters, Flight 8, RA-3B vs NC-117.

meters). This range includes the additional distance necessary because the display logic requires two successful tracks which correlate in range before a pilot display can be generated. The range required by ANTC-117 specifications, for a Tau-2 advisory at a closure rate of 550 knots (283 m/s), in order to produce the 51.8-second warning time is 8.98 nautical miles (16.6 kilometers). Thus, the reliable communication range established by the equipments during flight testing should be sufficient to provide the necessary advisories and commands with an acceptable number of late alarms. Significantly, the AVOID I utilized during flight tests did not incorporate the improvements in the AVOID system interrogation sequence, which should improve the communication reliability. The reliable communication range between an updated AVOID I and an AVOID II should be greater than that recorded during the AVOID II flight tests.

WARNING TIMES

The warning times provided by the AVOID I are consistent with ANTC-117 requirements. As described in the section titled, "Warning Time Statistics, Range and Range Rate Accuracies," the AVOID II provides fixed warning times for commands (25 seconds) and advisories (40 seconds). A comparison of the threat zone thresholds of the two AVOID equipments is contained in figure 33. The primary difference is the greatly reduced Tau-2 threat zone implemented by the AVOID II. Figure 34 is a plot of the measured range as a function of range rate of the aircraft at the time of the first threat display on the pilot's indicator during flight 6. For ease of comparison, the initial indications which occurred aboard each aircraft are plotted in the same figure. As the plot indicates, the AVOID I generated the required advisories with one delayed advisory resulting from incomplete communication sequences at the threat zone threshold. However, the advisory was still displayed with a warning time of 44.8 seconds. The required commands were all presented with an acceptable deviation from the ANTC-117 threshold.

During flight 7, the P-3A flew at an altitude of 9,800 feet (2.99 km) while the RA-3B flew at an altitude of 10,600 feet (3.23 km). Since AVOID I advisories and commands precede those provided by the AVOID II (see figure 34), a safe altitude separation is sometimes achieved prior to penetration of the AVOID II Tau-1 threshold. This is especially true for encounters with low closure rates. The AVOID II equipment was not required to generate commands due to the altitude separation. Since the AVOID II coaltitude zone is ±600 feet (±183 m) while the AVOID I co-altitude zone is ±800 feet (±244 m) during operation above 9600 feet (2.93 km), only the AVOID I was required to generate evasive commands to the pilot during flight 7, Figure 35 shows the threshold warning points which occurred during flight 7.

Due to the air speeds of the two aircraft involved and the encounter angles flown, the majority of closure rates which occurred during flight 7 were higher than 300 knots (154 m/s). At range rates above 320 knots (165 m/s), the AVOID II advisories are delayed due to the fixed tracking range of 4.2 nautical miles (7.8 km) and the display logic (two successive range correlated tracks). In a similar fashion, the commands provided for encounters with closure rates in excess of 420 knots (216 m/s) would be delayed. During the higher speed encounters, late commands would have occurred at the same time as the advisories shown if the altitude separation had been less.

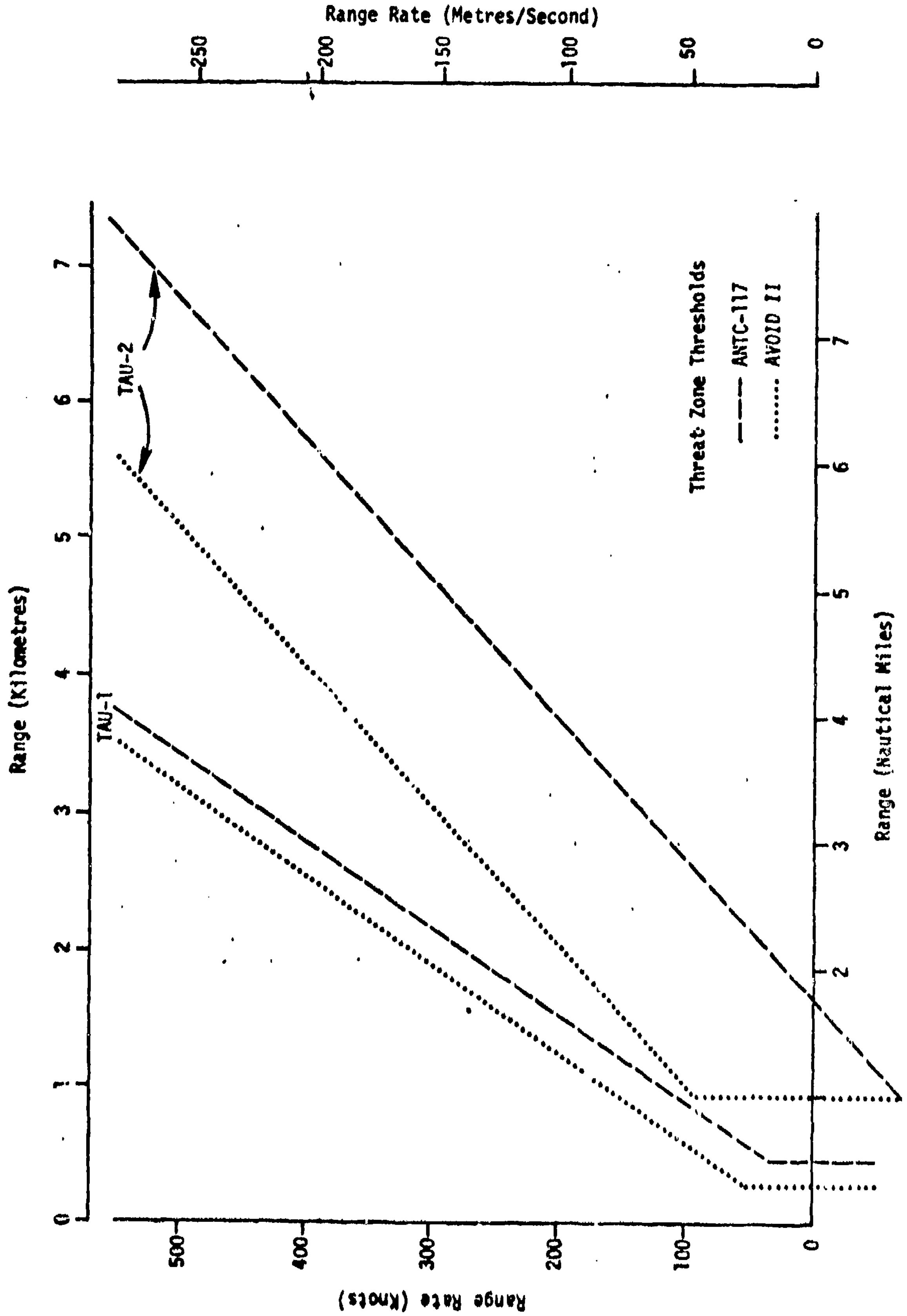


Figure 33. AVOID I and AVOID II Threat Zone Thresholds.

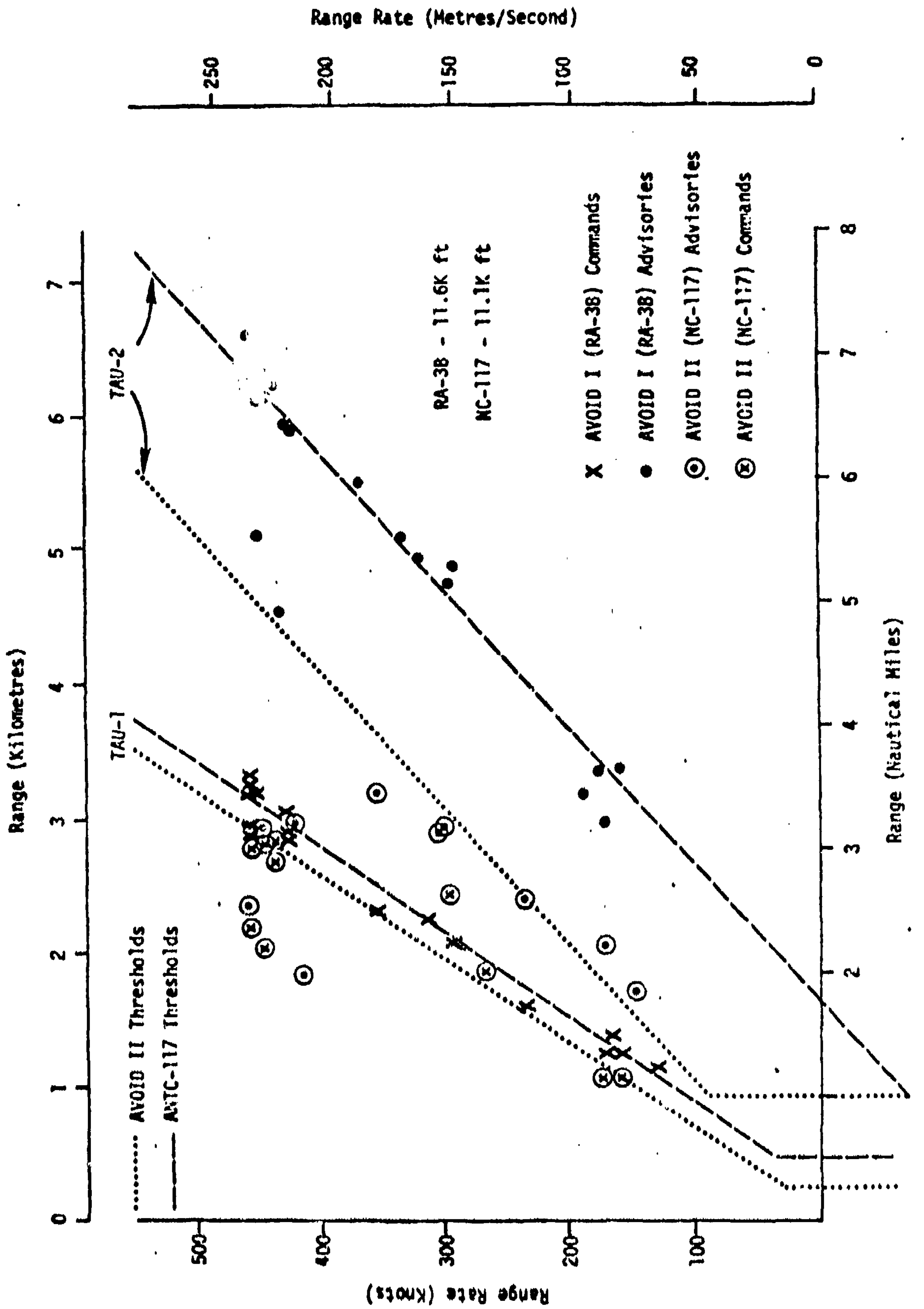


Figure 34. AVOID I and AVOID II Warning Threshold Plot, Flight 6, RA-3B vs NC-117.

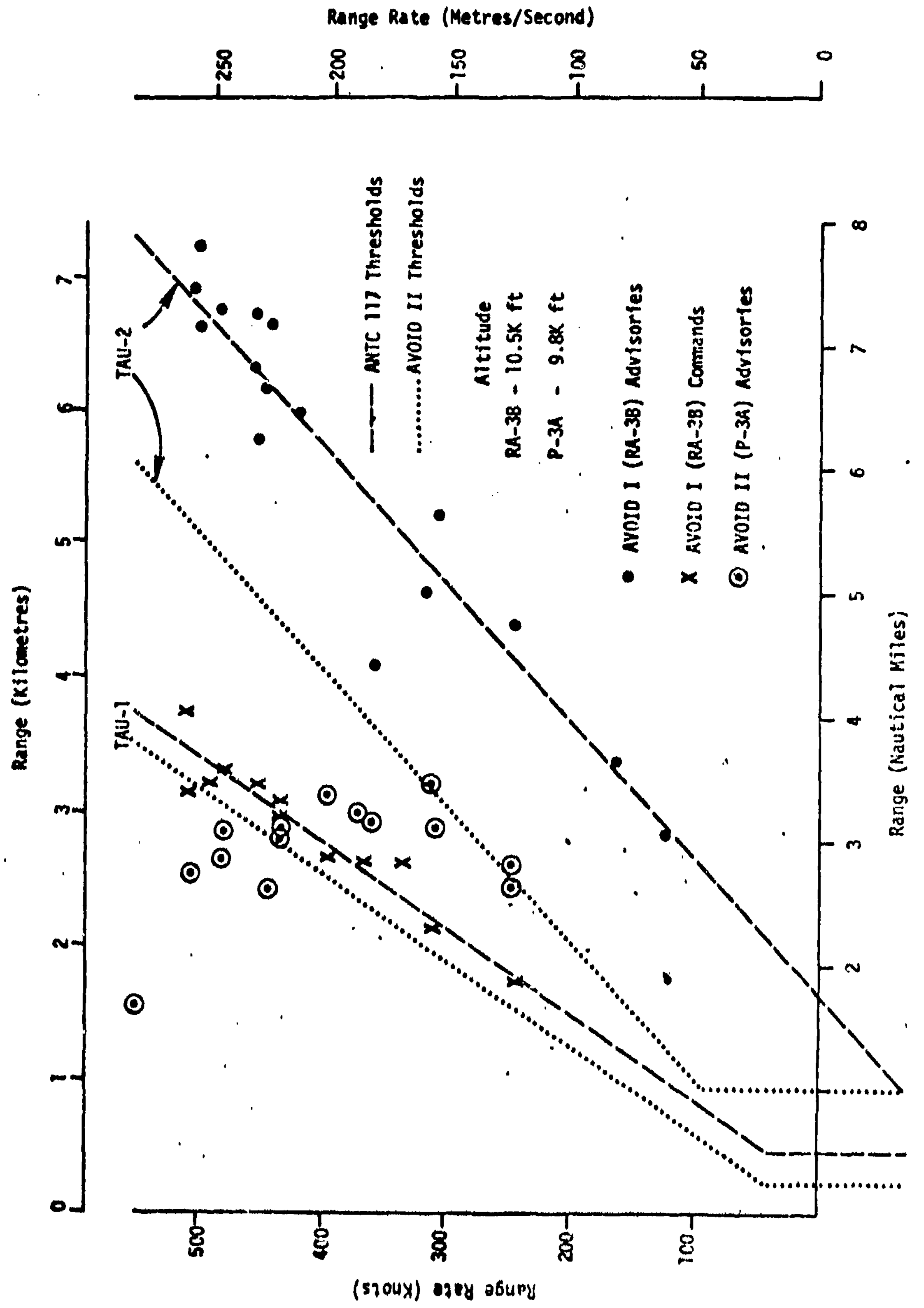


Figure 35. AVOID I and AVOID II Warning Threshold Plot, Flight 7, RA-3B vs P-3A.

Figure 36 is a plot of the threshold warning points which occurred during flight 8 for encounters between the RA-3B and the P-3A. During higher speed (near head-on) encounters, the NC-117 was at a closer range to the RA-3B than the P-3A when the P-3A crossed the Tau-2 threshold of the RA-3B. As a result of digital interface limitations, the measured range and range rate of the NC-117 and not that of the threatening intruder was recorded when the threat advisory to the pilot occurred. The figure shows the warning threshold points which occurred aboard the P-3A during the higher speed encounters without the points corresponding to displays which occurred aboard the RA-3B. The correct displays did occur aboard the RA-3B during these encounters, but accurate placement on the plot was not possible. The warning threshold points for the AVOID I equipment occurred within the acceptable tolerances of ANTC-117 requirements. Again, the AVOID II warning threshold points recorded during flight 8 show the affect of the limited tracking range.

Figure 37 shows the warning threshold points which were recorded aboard the RA-3B during the head-on encounters with the NC-117 during flight 8. The altitude separation between the RA-3B and the NC-117 varied between 1200 (366 m) and 1300 feet (396 m) during the encounters. The AVOID I utilized during flight tests evaluated target aircraft within ±1350 feet (±411 m) of relative altitude, and the AVOID II only evaluated those aircraft within ±1250 feet (±381 m). Consequently, warning threshold points could only be determined accurately from the data recorded aboard the RA-3B. Figure 37 clearly shows that the communication link sensitivity between the RA-3B and NC-117 was sufficient to permit Tau-2 advisories consistent with ANTC-117 requirements.

DISPLAY RELIABILITY

A measure of the compatibility of the AVOID II with the AVOID I is the display reliability achieved during the flight test encounters. Table XX lists the display and tracking reliabilities established aboard the AVOID I equipped RA-3B during flight tests. The values are listed as a function of encounter angle between aircraft. Table XXI is a comparison of the overall display and intruder tracking reliabilities achieved during the AVOID I flight tests as reported previously[5] and those achieved during the AVOID II flight tests. The reliabilities were determined separately for the RA-3B versus the NC-117 encounters and the RA-3B versus P-3A encounters. In all cases, the RA-3B flew patterns at an altitude above the other participating aircraft. The intruder tracking reliabilities exhibited no significant differences between the two separate flight test evaluations. However, the display reliabilities achieved aboard the AVOID I equipped aircraft during the AVOID II flight tests were several percent below those achieved previously.

Table XXII lists the display and tracking reliabilities established by the AVOID II during the compatibility flight tests as a function of encounter angle. The display and tracking reliabilities without regard to encounter angle, which were established aboard the NC-117 and the P-3A during encounters with the RA-3B,

[5]NAVAIRDEVCEN Final Report No. NADC-75056-60 Flight Test Evaluation of AVOID I Collision Avoidance System dated May 1075.

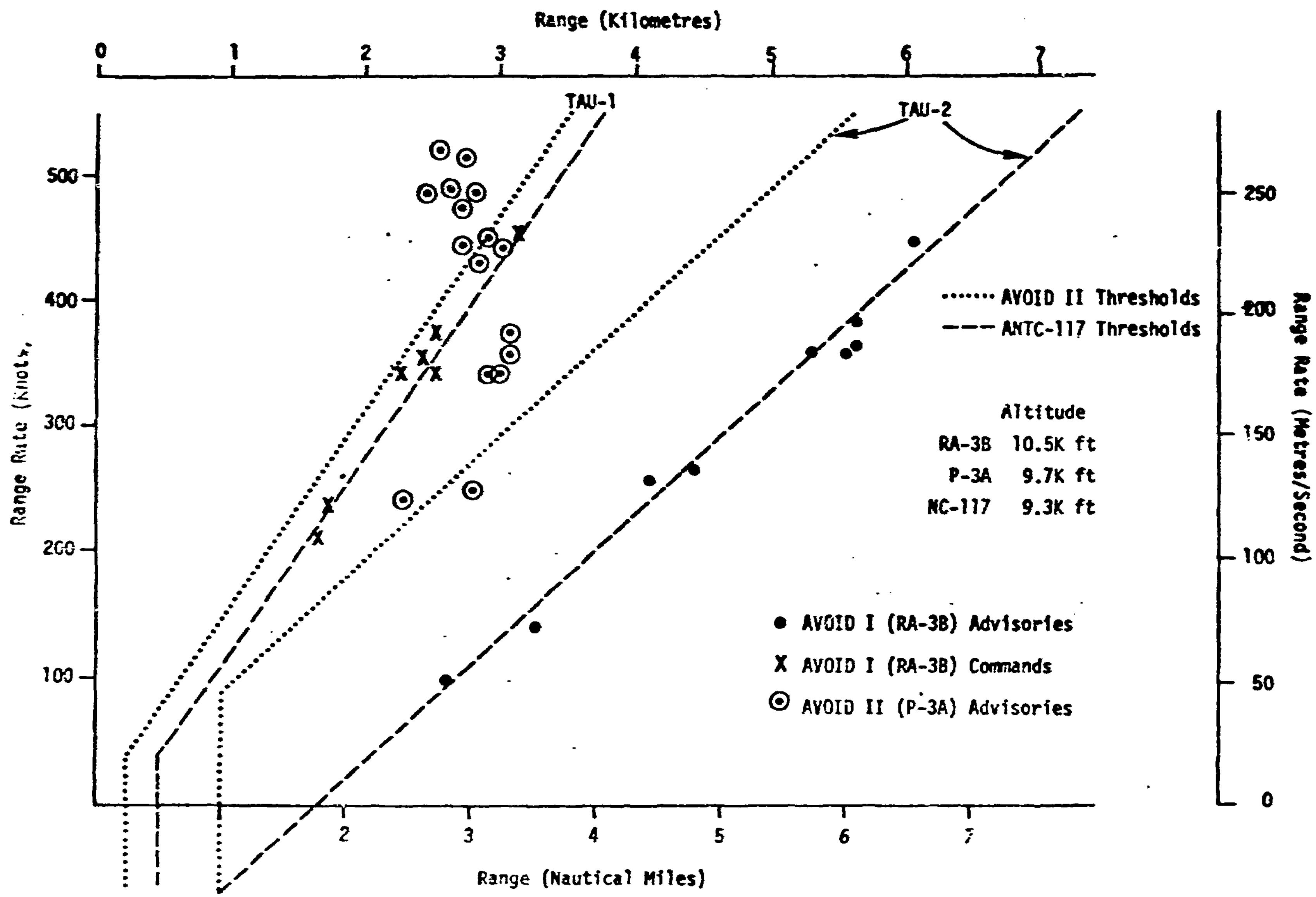


Figure 36. AVOID I and AVOID II Warning Threshold Plot, Flight 8, RA-3B vs P-3A.

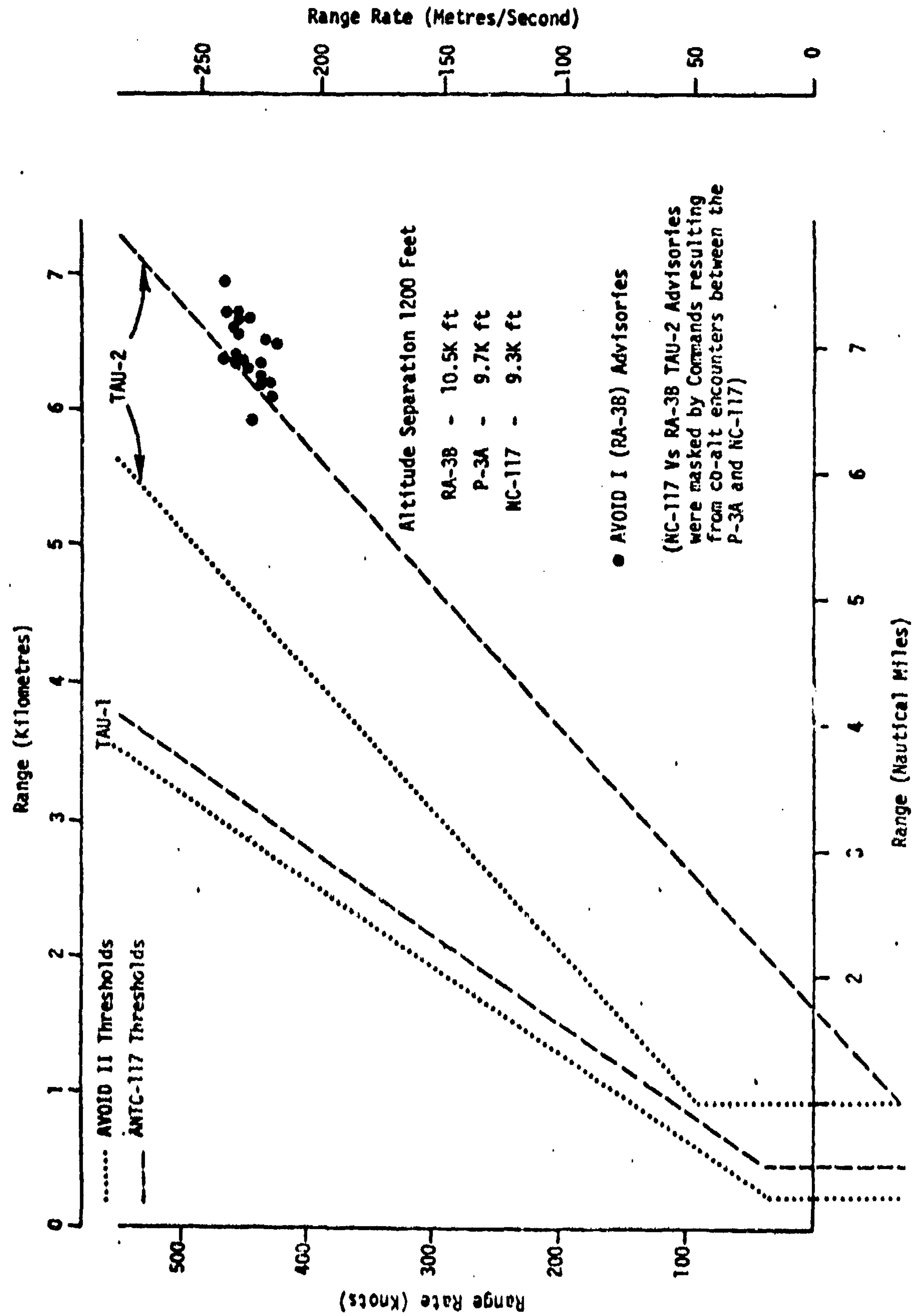


Figure 37. AVOID I Warning Threshold Plot, Flight 8, RA-3B vs NC-117.

TABLE XX. AVOID I VS AVOID II DISPLAY AND INTRUDER TRACKING RELIABILITY AS A FUNCTION OF ENCOUNTER ANGLE

Encounter Angle	180	150	120	90	60	30	0	-30	-60	-90	-120	-150
Intruder Tracking Reliability	$\frac{666}{694}$ 0.960	$\frac{94}{101}$ 0.931	$\frac{86}{93}$ 0.925	$\frac{118}{126}$ 0.937	$\frac{159}{162}$ 0.981	$\frac{182}{199}$ 0.915	$\frac{198}{208}$ 0.952	$\frac{194}{208}$ 0.933	$\frac{106}{113}$ 0.938	$\frac{65}{73}$ 0.890	$\frac{54}{55}$ 0.982	$\frac{44}{46}$ 0.957
Display Reliability	$\frac{447}{472}$ 0.947	$\frac{67}{72}$ 0.931	$\frac{85}{93}$ 0.914	$\frac{80}{82}$ 0.976	$\frac{94}{94}$ 1.00	$\frac{35}{35}$ 1.00	$\frac{108}{108}$ 1.00	$\frac{128}{128}$ 1.00	$\frac{44}{44}$ 1.00	$\frac{32}{40}$ 0.800	$\frac{38}{38}$ 1.00	$\frac{34}{36}$ 0.944

Overall Display Reliability

$$\frac{1192}{1242} = 0.960$$

Overall Intruder Tracking Reliability

$$\frac{1966}{2078} = 0.946$$

TABLE XXI. RELIABILITIES ACHIEVED ABOARD THE RA-3B DURING AVOID I (1974) AND AVOID II (1975) FLIGHT TESTS

	Display Reliability		Intruder Tracking Reliability	
	AVOID I Flight Test	AVOID II Flight Test	AVOID I Flight Test	AVOID II Flight Test
RA-3B vs NC-117	$\frac{704}{711} = 0.990$	$\frac{724}{746} = 0.971$	$\frac{977}{1022} = 0.956$	$\frac{1041}{1088} = 0.957$
RA-3B vs P-3A	$\frac{877}{897} = 0.977$	$\frac{468}{496} = 0.944$	$\frac{999}{1056} = 0.946$	$\frac{925}{990} = 0.934$

TABLE XXII. AVOID II VS AVOID I DISPLAY AND INTRUDER TRACKING RELIABILITIES AS A FUNCTION OF ENCOUNTER ANGLE, P-3A AND NC-117 VS RA-3B

Encounter Angle	180	150	120	90	60	30	0	-30	-60	-90	-120	-150
P-3 vs A-3 Display Reliability	$\frac{24}{24}$ 1.00	$\frac{25}{25}$ 1.00	$\frac{28}{28}$ 1.00	$\frac{40}{40}$ 1.00	$\frac{46}{48}$ 0.958	$\frac{24}{24}$ 1.00	$\frac{29}{29}$ 1.00	$\frac{12}{13}$ 0.923	$\frac{19}{19}$ 1.00	$\frac{43}{43}$ 1.00	$\frac{28}{31}$ 0.903	$\frac{29}{29}$ 1.00
NC-117 vs A-3 Display Reliability	$\frac{67}{67}$ 1.00	$\frac{6}{8}$ 0.750	$\frac{13}{13}$ 1.00	$\frac{11}{11}$ 1.00	$\frac{22}{24}$ 0.916	-	$\frac{32}{32}$ 1.00	$\frac{28}{28}$ 1.00	-	-	-	-
P-3 vs A-3 Tracking Reliability	$\frac{24}{24}$ 1.00	$\frac{27}{27}$ 1.00	$\frac{30}{31}$ 0.968	$\frac{40}{40}$ 1.00	$\frac{53}{55}$ 0.964	$\frac{111}{111}$ 1.00	$\frac{146}{146}$ 1.00	$\frac{30}{30}$ 1.00	$\frac{51}{51}$ 1.00	$\frac{46}{46}$ 1.00	$\frac{33}{35}$ 0.943	$\frac{30}{30}$ 1.00
NC-117 vs A-3 Tracking Reliability	$\frac{164}{167}$ 0.982	$\frac{12}{13}$ 0.923	$\frac{13}{13}$ 1.00	$\frac{11}{11}$ 1.00	$\frac{25}{28}$ 0.893	$\frac{17}{25}$ 0.680	$\frac{38}{39}$ 0.974	$\frac{39}{46}$ 0.848	-	-	-	-

are compared with the results of the previous AVOID I flight test in table XXIII. The tracking reliability as well as the display reliability exhibited an improvement during AVOID II flight tests. This improvement was mainly due to the improved interrogation sequence and altitude scale factor. However, it was also the result of a reduced tracking range with a power budget capable of a greater communication range.

The compatibility flight tests demonstrated that the AVOID II provides responses to the AVOID I interrogations which enable the AVOID I to process intruders both accurately and reliably, and to provide warning times consistent with ANTC-117 requirements. Similarly, the AVOID II was capable of processing AVOID I responses both accurately and reliably, and the AVOID II was able to provide warning times consistent with AVOID system specifications for general aviation requirements.

WARNING TIME STATISTICS, RANGE AND RANGE RATE ACCURACIES

INTRODUCTION

The function of a CAS is to detect aircraft which constitute a potential threat, evaluate the seriousness of the threatening situation, and display to the pilot an advisory or maneuver indication which is required in time to maintain safe operation. In addition, it is necessary that the collision avoidance system's alarm region be less than the air traffic control separation being employed, otherwise the alarm rate and interaction on ATC would be unacceptable.

The airline operational and functional requirements for such a collision avoidance system were issued by the Air Transport Association in the Air Navigation/Traffic Control report number 117 (ANTC-117). The AVOID I CAS was designed and built consistent with the requirements of ANTC-117. The AVOID II system, however, is designed especially for use in relatively low speed, primarily VFR, aircraft. Since these aircraft have different performance characteristics and normally operate in a different environment than do air carrier or other high performance aircraft, the AVOID II system design deviates in some aspects from the requirements established in ANTC-117. One such aspect is the warning time or Tau threat zone thresholds. The threat zone thresholds for Tau-1 alarms and Tau-2 advisories are shown in figure 38. The resultant required warning times vary as a function of the closure rate between aircraft. This effect is due to the range offset or non-zero intercepts of the threshold lines. The Tau-1 threshold intercept is offset by 0.25 nautical miles (463 m) and the Tau-2 threshold intercept is offset by 1.8 nautical miles (3.3 km). In addition, a minimum range warning zone of a 1/2-nautical mile is included as an extension of the Tau-1 threat zone to compensate for range rate measurement errors, and provide some protection in potential turn maneuver situations. The slopes of the Tau threat zone thresholds of the AVOID II are the same as those of ANTC-117. That is, the inverse of the slope of the Tau-1 and Tau-2 zone thresholds are 25 and 40 seconds, respectively. The main deviations of the AVOID II system design from ANTC-117 requirements are the lack of range offsets, and the addition of a Tau-2 minimum range. In the AVOID II, the Tau-1 minimum range is 0.25

TABLE XXIII. RELIABILITIES ACHIEVED ABOARD THE NC-117 AND THE P-3A DURING AVOID I AND AVOID II FLIGHT TESTS

	Display Reliability		Intruder Tracking Reliability	
	AVOID I Flight Test	AVOID II Flight Test	AVOID I Flight Test	AVOID II Flight Test
P-3A vs RA-3B	$\frac{912}{937} = 0.973$	$\frac{347}{353} = 0.983$	$\frac{1217}{1276} = 0.954$	$\frac{620}{625} = 0.992$
NC-117 vs RA-3B	$\frac{471}{482} = 0,977$	$\frac{179}{183} = 0.978$	$\frac{742}{798} = 0.930$	$\frac{319}{342} = 0.933$

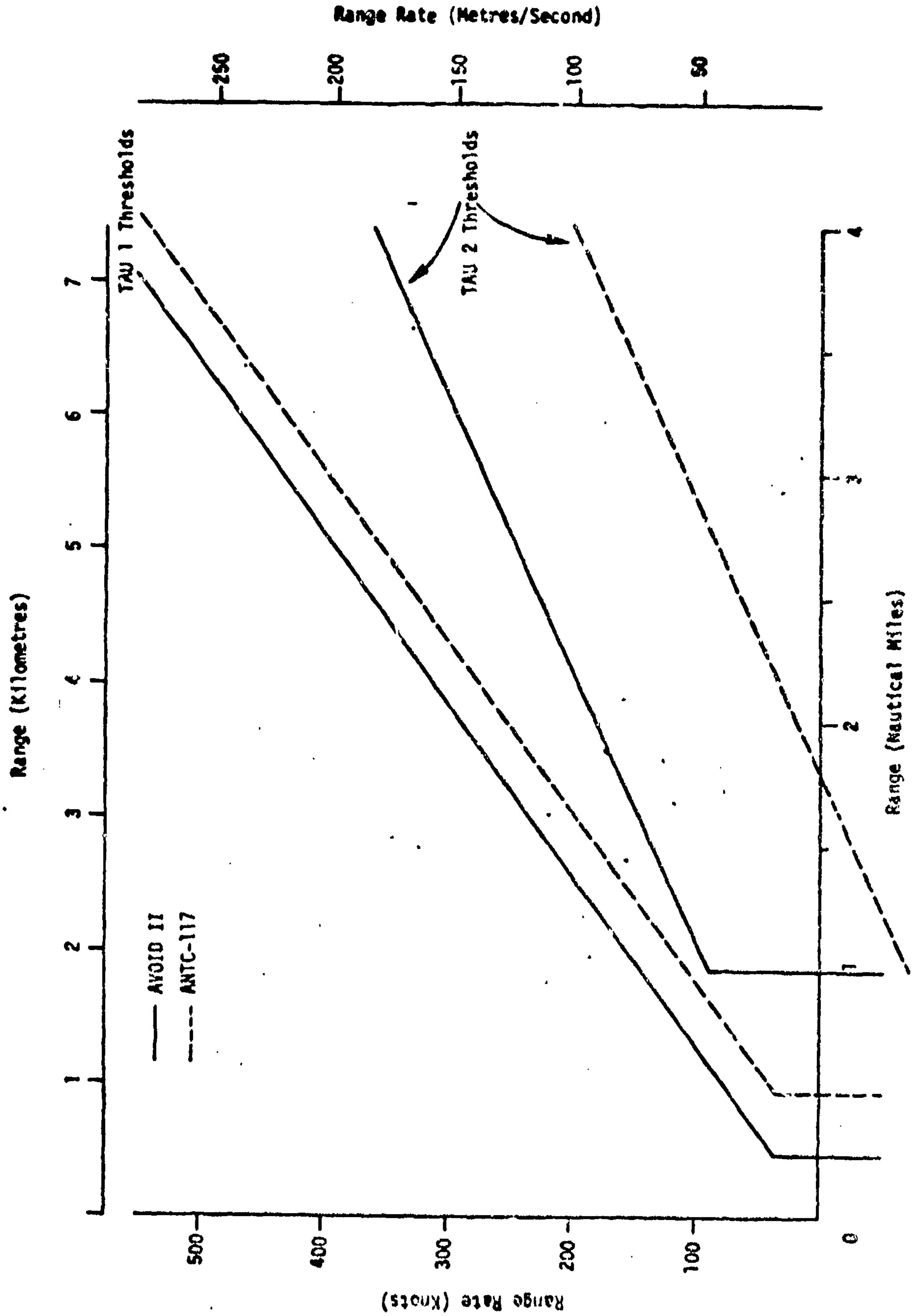


Figure 38. Threat Zone Thresholds, AVOID II and ANTC-117.

nautical miles (463 m) as opposed to 1/2 nautical mile in the ANTC-117 requirements. The Tau-2 minimum range of the AVOID II is 1 mile. In addition, intruders within the Tau-2 threat zone with closure rates between 50 feet per second (15.2 m/s) and -80 feet per second (-24 m/s) are distinguished by the AVOID II. In such situations a co-altitude threat is indicated by a steady light as opposed to the flashing range light which occurs when the range rate is greater than 50 feet per second (15.2 m/s). This allows the reduction of the large range offset which protects aircraft on parallel courses from turning maneuvers which might result in head-on encounters. The range offset required by ANTC-117 results in a significantly larger Tau-2 threat zone as shown in figure 38.

The maximum tracking range of the AVOID II has a significant affect on the warning times generated by the equipment. The 50-foot wide (15.2 meters) range bins implemented in the AVOID II equipment extend to 25,600 feet (7.8 kilometers). This range, in conjunction with the AVOID II mean processing round time of 3.7 seconds and display logic, which requires the presence of a threat during two successive communication rounds prior to the generation of a cockpit indication, results in actual Tau-2 warning times which are dependent to a certain extent on the closure rate between aircraft. The Tau-2 warning times which should be 40 seconds are reduced when the closure rate exceeds 325 knots (167 m/s). Similarly, the Tau-1 warning time of 25 seconds is reduced in the event of near head-on encounters with closure rates in excess of 425 knots (219 m/s). The majority of encounters between AVOID II equipped aircraft will occur with closure rates well below 325 knots (167 m/s) due to the lower air speeds of the aircraft for which the AVOID II is designed. Table XXIV shows the warning times possible as a function of closing rate for AVOID II equipped aircraft. It is important to realize that AVOID II equipped aircraft should not be capable of involvement in high speed encounters. Figure 39 is a plot of the Tau-1 and Tau-2 threat zone thresholds incorporated in the AVOID II threat evaluation process. The dashed lines shown represent the earliest display possible (D_E) and the latest display (D_L) which occur during normal operating conditions at high closure rates. These two lines are the result of the fixed tracking range of 25,600 feet (7.8 km) and the display logic which requires two successive threat evaluations which are correlated in range. The earliest display can occur only after two rounds of communication. The AVOID II round time varies between 3.5 and 3.9 seconds in order to enhance the asynchronous properties of the AVOID system. The mean duration of two rounds of communication is then 7.4 seconds. For example, two aircraft with a closure rate of 450 knots (231 m/s) would be 0.93 nautical miles (1.7 km) closer after 7.4 seconds. Since the AVOID II maximum tracking range is 4.19 nautical miles (7.76 km), the earliest display could only occur at a range of 3.26 nautical miles (6.04 km). A display which occurs at that range with a closure rate of 450 knots (231 m/s) results in a warning time of 26.1 seconds. However, two aircraft can cross the 4.19 nautical miles (7.76 km) range tracking threshold at any time during a communication round. Since two complete tracking sequences are necessary to generate a display, the first pilot display will occur at a time between two and three round times (7.4 to 11.1 seconds on the average) after tracking begins since the aircraft might not have been within tracking range at the start of the earliest sequence of interrogations. Two aircraft with a closure rate of 450 knots (231 m/s) would be 1.39 nautical miles (2.57 km) closer after 3 rounds (11.1 seconds). Such a display would occur at a range of 2.80 nautical miles (5.19 km) which represents a warning time of 22.4 seconds. Thus aircraft with a closure rate of 450 knots (231 m/s) could receive

TABLE XXIV. AVOID II RANGE AND WARNING TIME PROVIDED BY EARLIEST DISPLAY AT HIGHER CLOSURE RATES

Closure Rate	Range at Display (nmi)	Maximum Warning Time
300	3.57	42.9
325	3.52	39.0
350	3.47	35.7
375	3.42	32.8
400	3.37	30.3
425	3.32	28.1
450	3.26	26.1
475	3.21	24.3
500	3.16	22.8
525	3.11	21.3
550	3.06	20.0

Note: Displays can occur with as much as 3.7 seconds less warning time than the amount shown

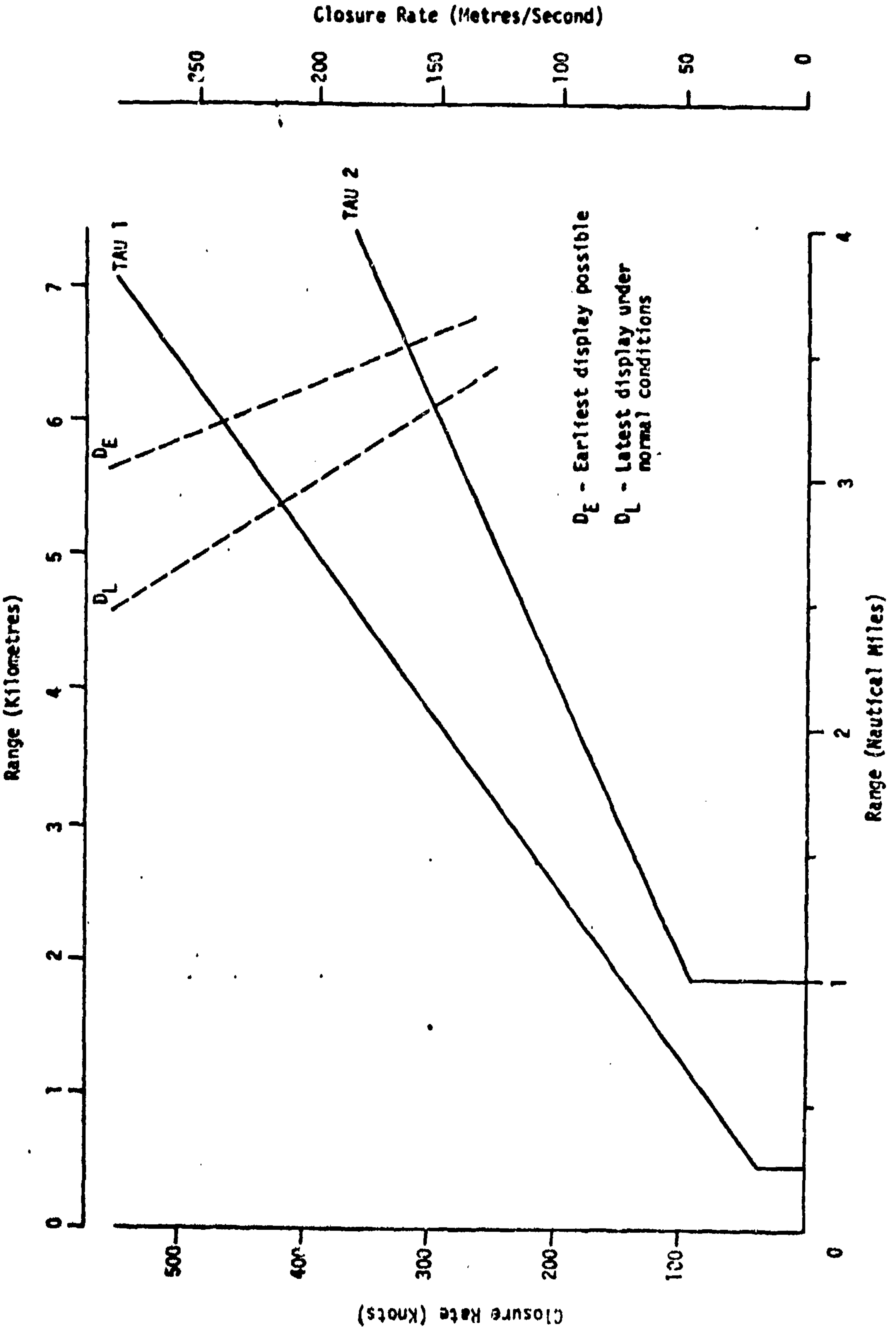


Figure 39. Display Threshold at High Range Rates.

a display with a warning time from 22.4 up to 26.1 seconds prior to the closest point of approach. Figure 40 shows the theoretical mean warning time of the first display which can be supplied by an AVOID II equipment as a function of the closure rate between aircraft. The Tau-1 and Tau-2 warning times which are consistent with ANTC requirements are also plotted.

AVOID II VS AVOID II WARNING TIME STATISTICS

Table XXV shows the results of the encounters flown during flight 2 to compare warning times generated at different closure rates but at the same encounter angle (head-on encounters in this case).

TABLE XXV. ACTUAL MEAN WARNING TIMES PROVIDED AT VARIOUS CLOSURE RATES

Closure Rate (knots)	Time (seconds)	
	TAU-1	TAU-2
355 (183 m/s)	25.9	34.7
430 (221 m/s)	25.7	--

The only significant difference between the two groups of data was the lack of a Tau-2 advisory display during the encounters at the higher closure rate.

The advisory and command warning times generated during the flight test encounters were determined on the basis of the range and closure rate between aircraft at the time the pilot's display was updated. The closure rate was calculated by dividing the result of the difference between range measurements preceding and following the event when the threat was displayed by the time interval separating the two measurements. This method resulted in estimates of closure rate based on a 7.4-second mean time base. The range and range rate of the initial advisory and command displayed to the pilot during flight 4 aboard the P-3A are plotted in figure 41. Advisories and commands which fall to the left of the respective Tau threshold lines are considered to be late, while those which fall to the right are considered to be early. The one late command which occurred aboard the P-3A was the consequence of incorrect altitude exchange which resulted when the NC-117 initiated an altitude bias just prior to changing altitude. That is, the initial altitude separation was 400 feet (122 m) (requiring the altitude bias) but upon changing altitude as a result of the command display, the altitude separation was 500 feet (152 m) which in addition to the 200-foot (61 m) bias resulted in an apparent 700-foot (213 m) altitude separation to the P-3A. The P-3A identified the correct threat as soon as the bias was removed aboard the NC-117 resulting in a 19.5-second warning time. Figure 42 is a plot

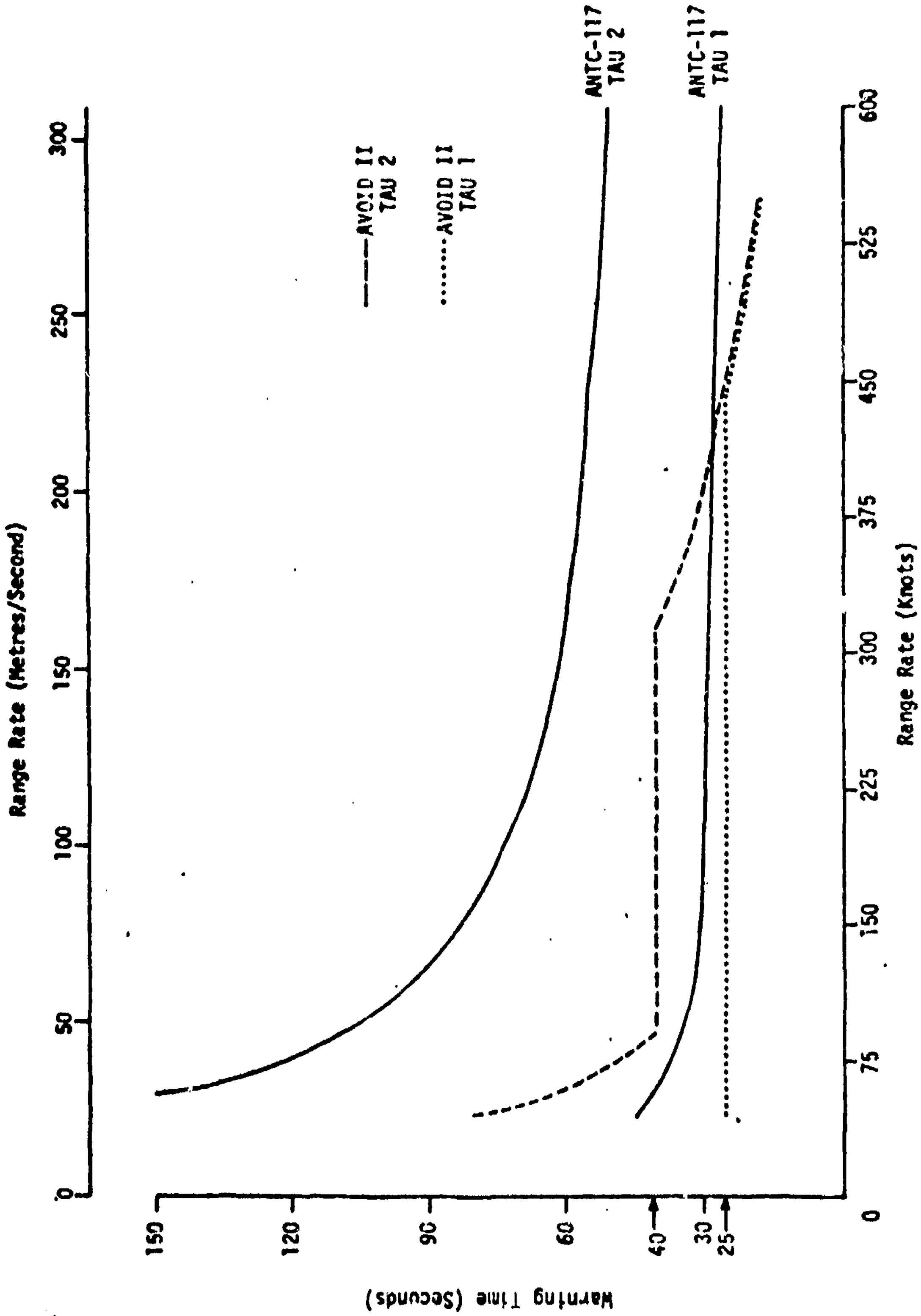


Figure 40. AVOID II Mean Warning Time (Theoretical).

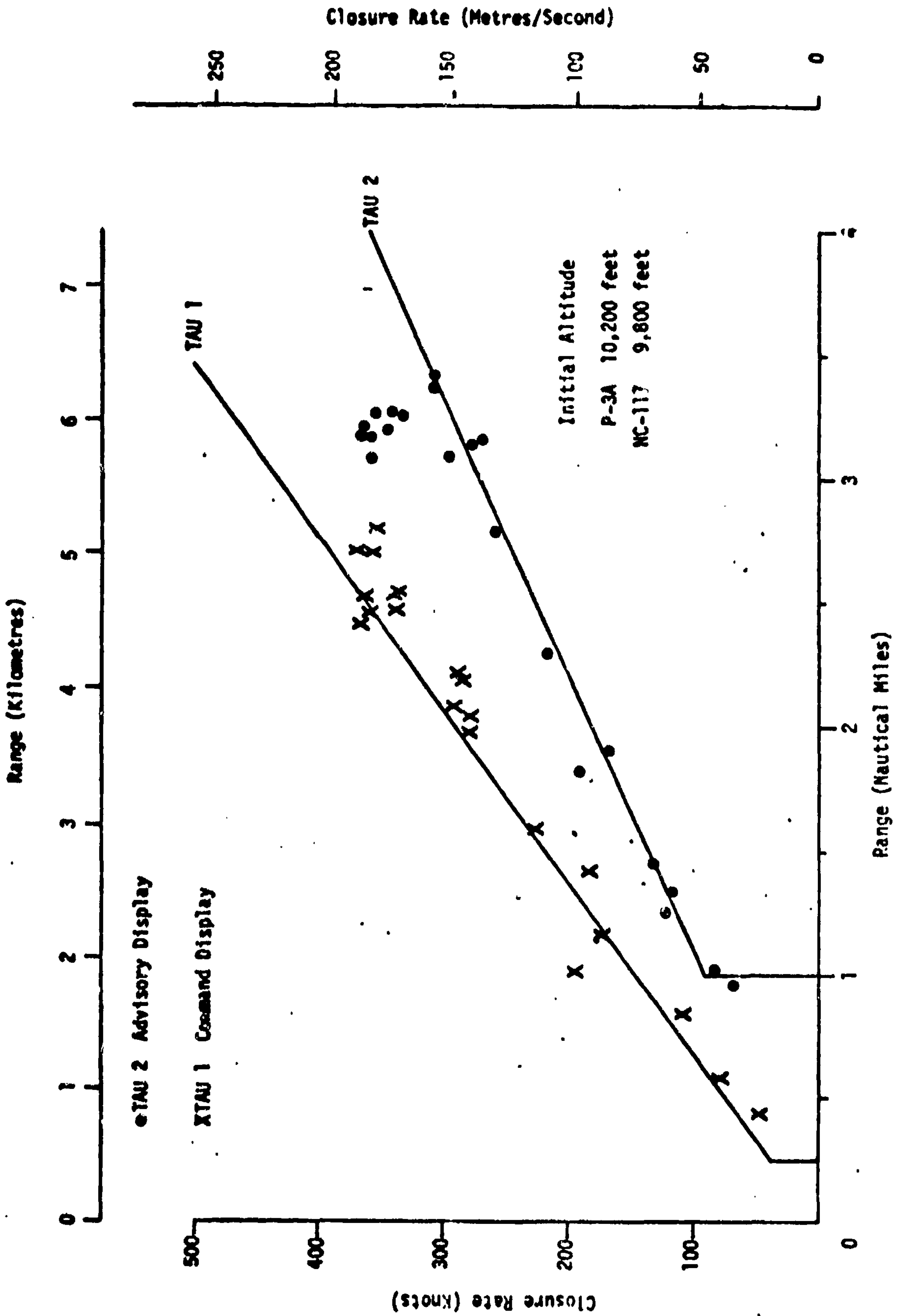


Figure 41. AVOID II Warning Threshold Plot, Flight 4, P-3A vs NC-117.

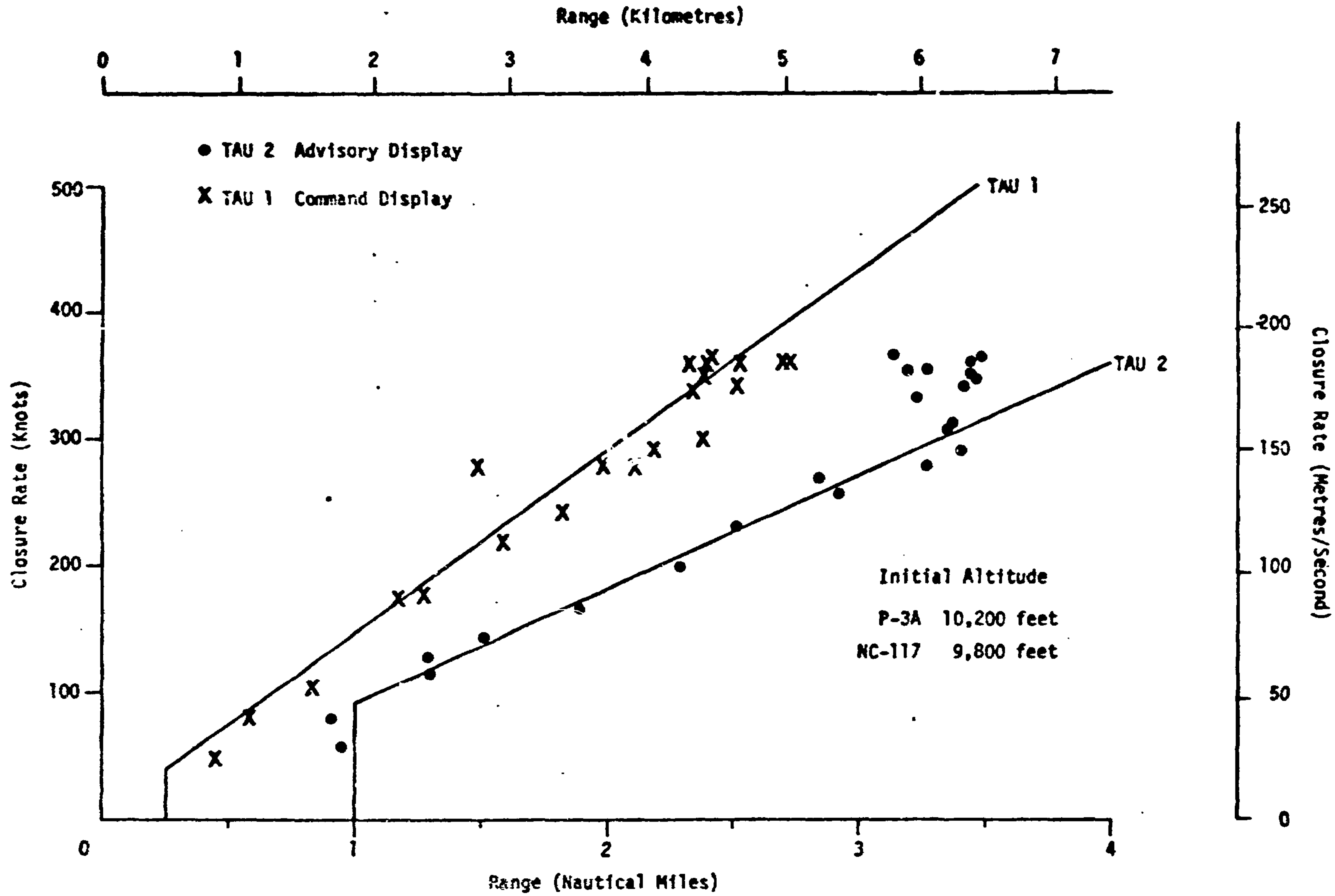


Figure 42. AVOID II Warning Threshold Plot, Flight 4, NC-117 vs P-3A.

of the corresponding threshold warning times which occurred aboard the NC-117 during flight 4. One late command with a warning time of 18.8 seconds occurred as a result of an incorrect altitude decode just after the Tau-1 threshold was penetrated, requiring the occurrence of two additional Tau-1 threat identifications prior to a display to the pilot. The Tau-2 advisories aboard both aircraft during flight 4 occurred with the proper warning times for closure rates up to 300 knots (154 m/s).

The AVOID II advisory and command warning threshold values which occurred aboard the P-3A during flight 5 are plotted in figure 43. No late commands occurred; however, one command resulted in a warning time of almost 31 seconds. This large warning time resulted because the closure rate between aircraft was decreasing rapidly (approximately 15 knots (7.7 m/s) per second) at the time the Tau-1 threshold was penetrated. Figure 44 shows the warning thresholds which occurred aboard the NC-117 during flight 5. One late command occurred with a warning time of 18.4 seconds. This late command resulted from a tracking failure at the time the Tau-1 threshold was penetrated. The Tau-2 warnings occurred within acceptable limits for encounters with closure rates less than 325 knots (167 m/s) during flight 5.

Warning thresholds which occurred as a result of encounters between the AVOID II equipped aircraft during flight 8 are shown in figure 45 and 46. Flight 8 consisted of encounters which involved three aircraft, one of which was equipped with an AVOID I CAS. The data pertaining to AVOID I versus AVOID II operation is discussed in the section titled, "AVOID I - AVOID II Compatibility," Figure 45 shows the range and closure rate of each pilot display initiation aboard the NC-117 as a result of the P-3A. All command displays occurred within one round time (mean of 3.7 seconds) of the 25-second threshold. Similarily, command warning times which occurred aboard the P-3A as a result of the NC-117 (see figure 46) were also within one mean cycle time of the threshold. The Tau-2 advisories aboard both aircraft occurred at the proper times for closure rates up to 300 knots (154 m/s).

The plots of the range and closure rate at the time of the first threat display demonstrate that the AVOID II can consistently identify a 25-second Tau-1 threshold for closure rates which result during encounters between AVOID II equipped aircraft. The plots also demonstrate the AVOID II's ability to generate 40-second Tau-2 advisories during the same encounters with closure rates as high as 300 knots (154 m/s). The warning time reductions due to the maximum tracking range are clearly visible in the plots representing Tau-2 advisories for encounters with closure rates in excess of 300 knots (154 m/s).

The mean Tau-2 warning times generated as a function of encounter angle are plotted in figure 47. The brackets represent the standard deviation of the group of warning times evaluated. Similarly, the Tau-1 warning times generated as a function of encounter angle are shown in figure 48. The warning times generated at the zero degree or tail chase encounter angle are greater than 40 seconds for Tau-2 advisories due to the 6000 foot (1829 m) minimum range incorporated in the AVOID II threat zone. A similar, though much smaller, effect would appear on the Tau-1 plot if closing rates of less than 40 knots (21 m/s) had occurred during flight testing.

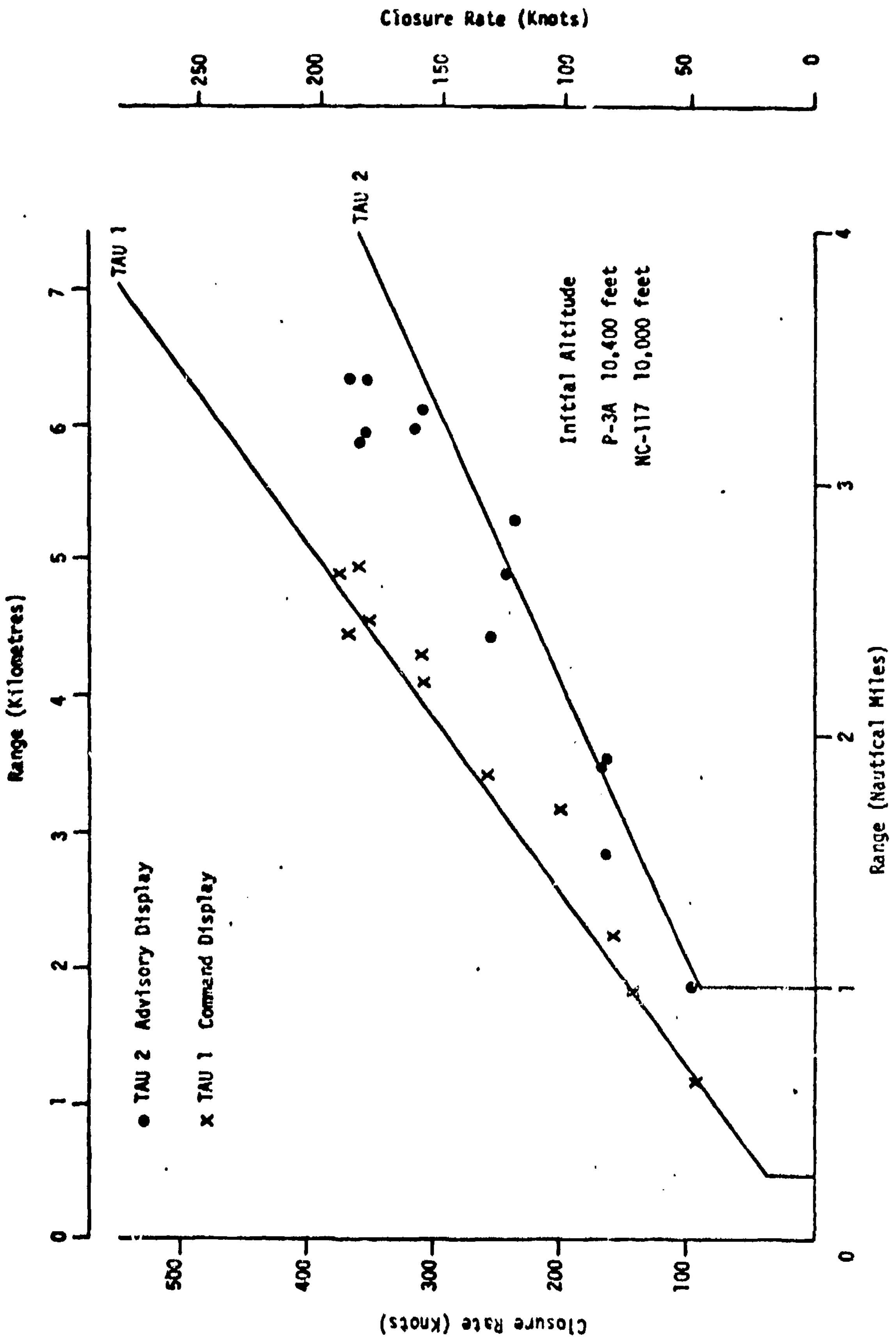


Figure 43. AVOID II Warning Threshold Plot, Flight 5, P-3A vs NC-117.

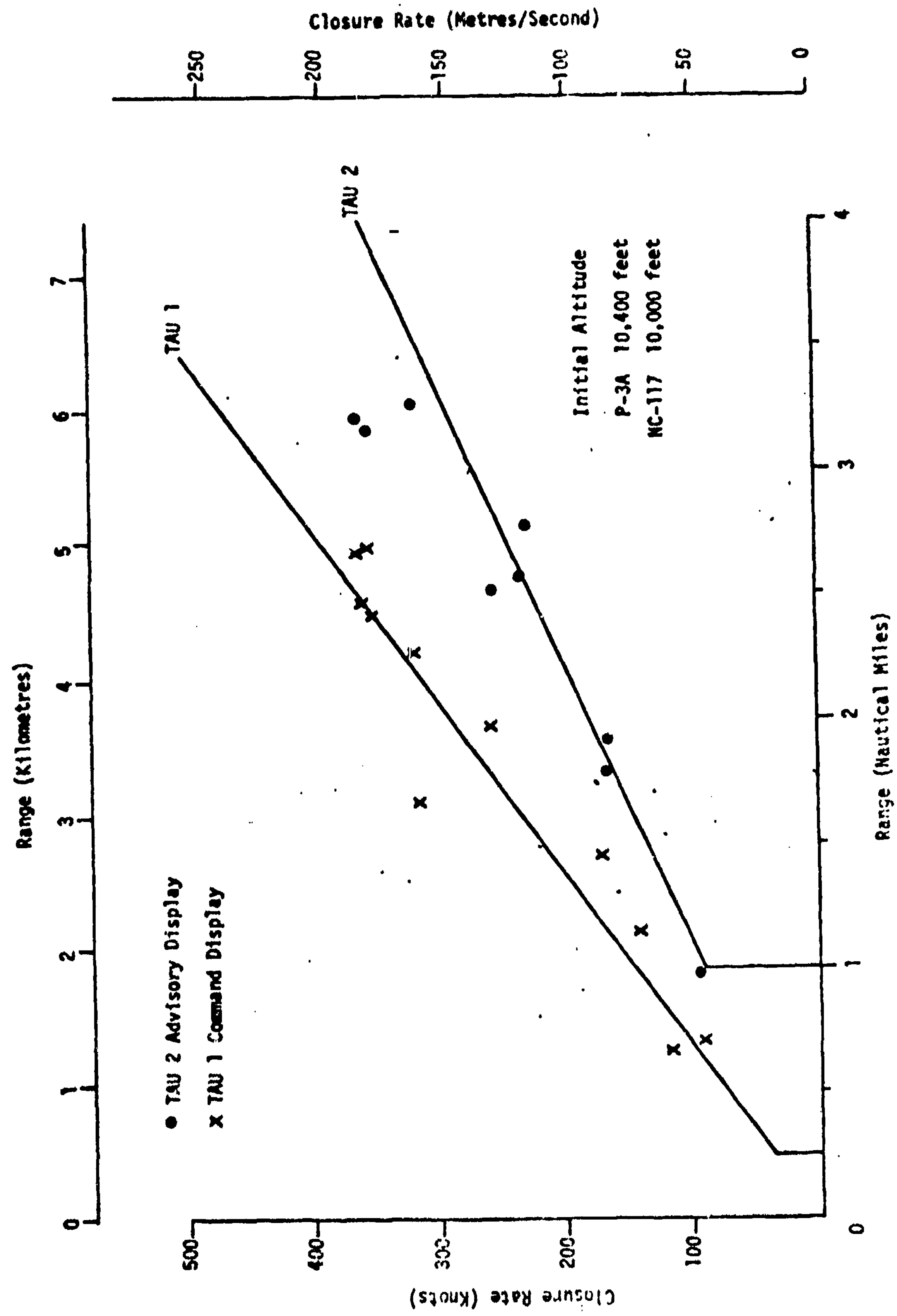


Figure 44. AVOID II Warning Threshold Plot, Flight 5, NC-117 vs P-3A.

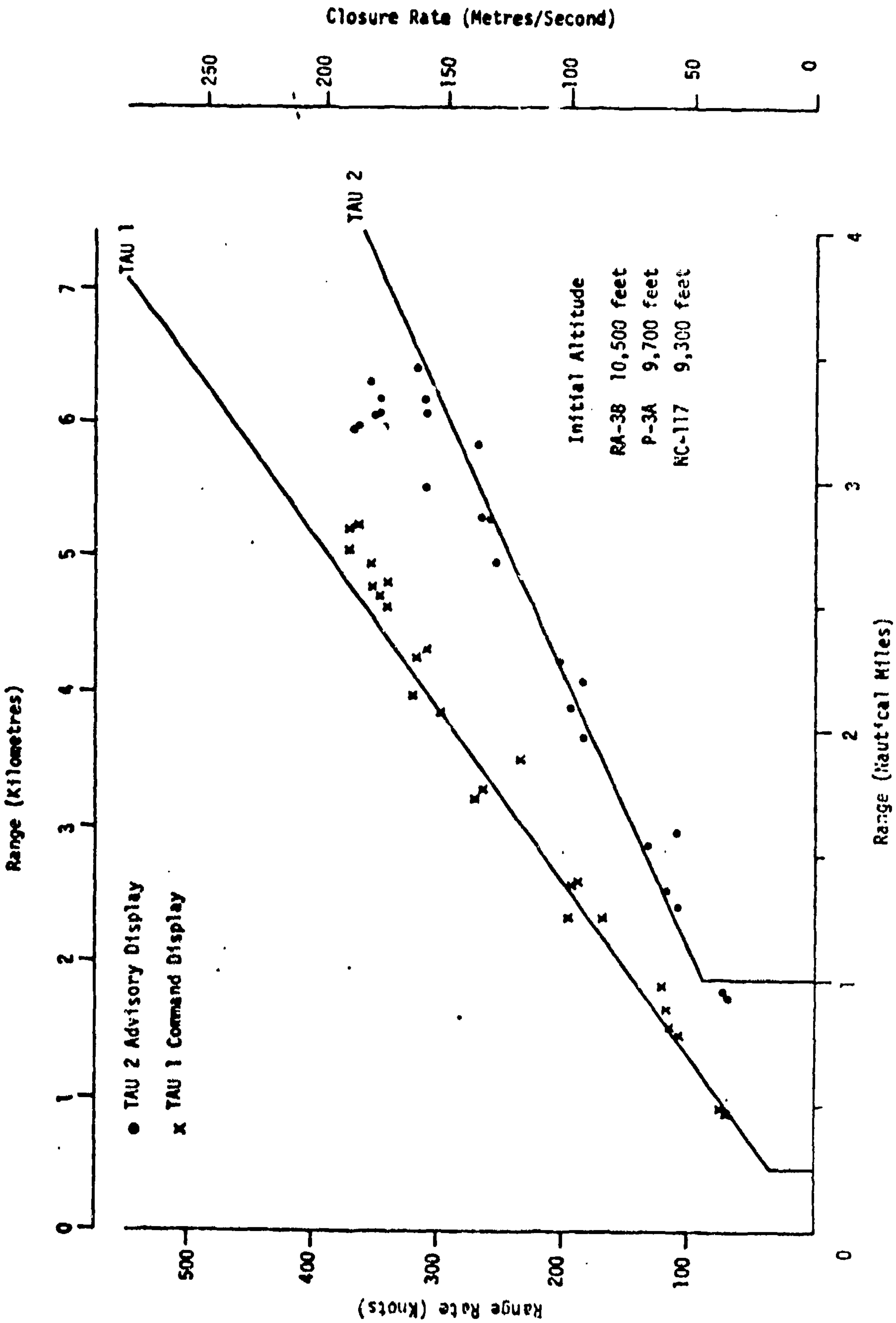


Figure 45. AVOID II Warning Threshold Plot, Flight 8, NC-117 vs P-3A.

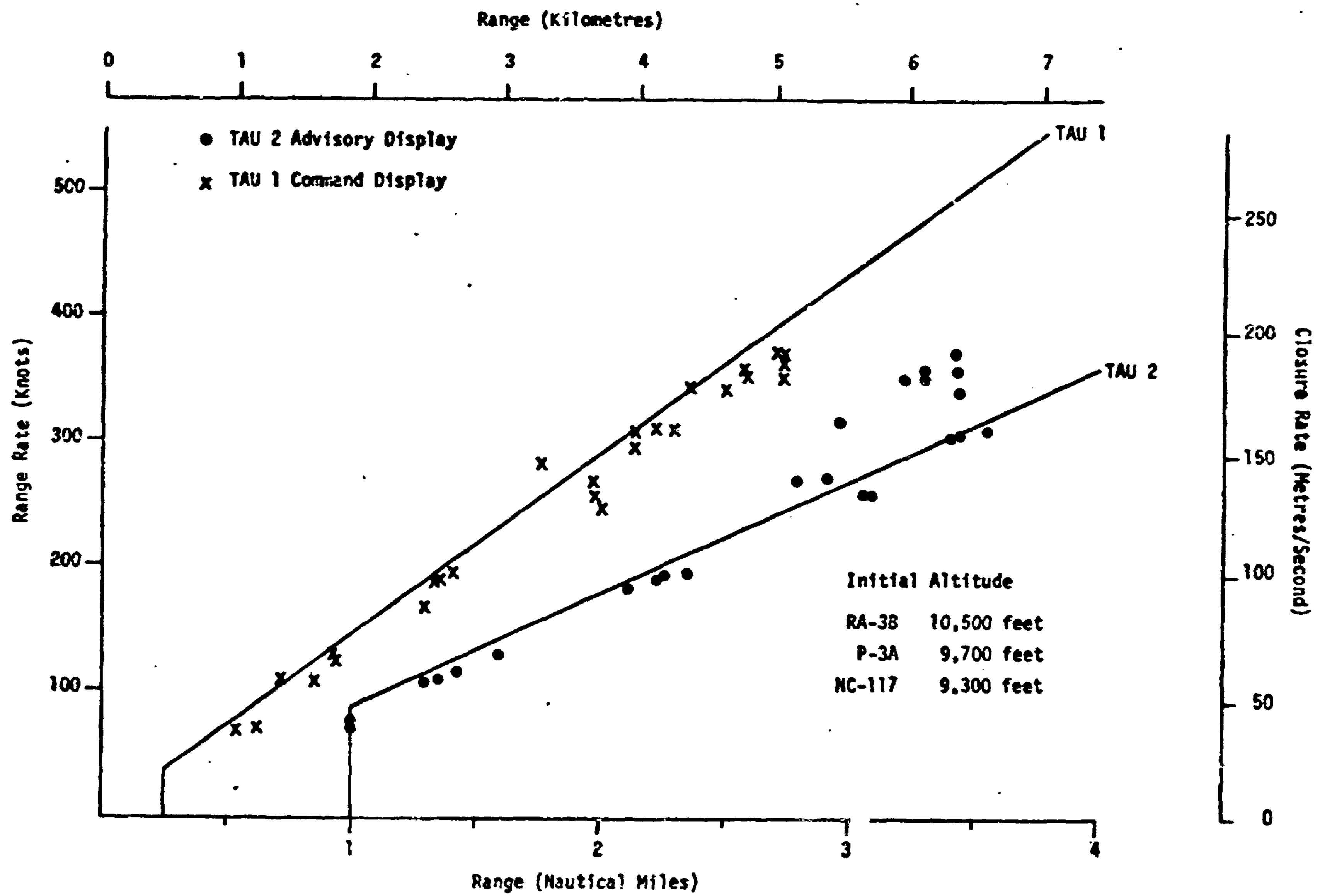


Figure 46. AVOID II Warning Threshold Plot, Flight 8, P-3A vs NC-117.

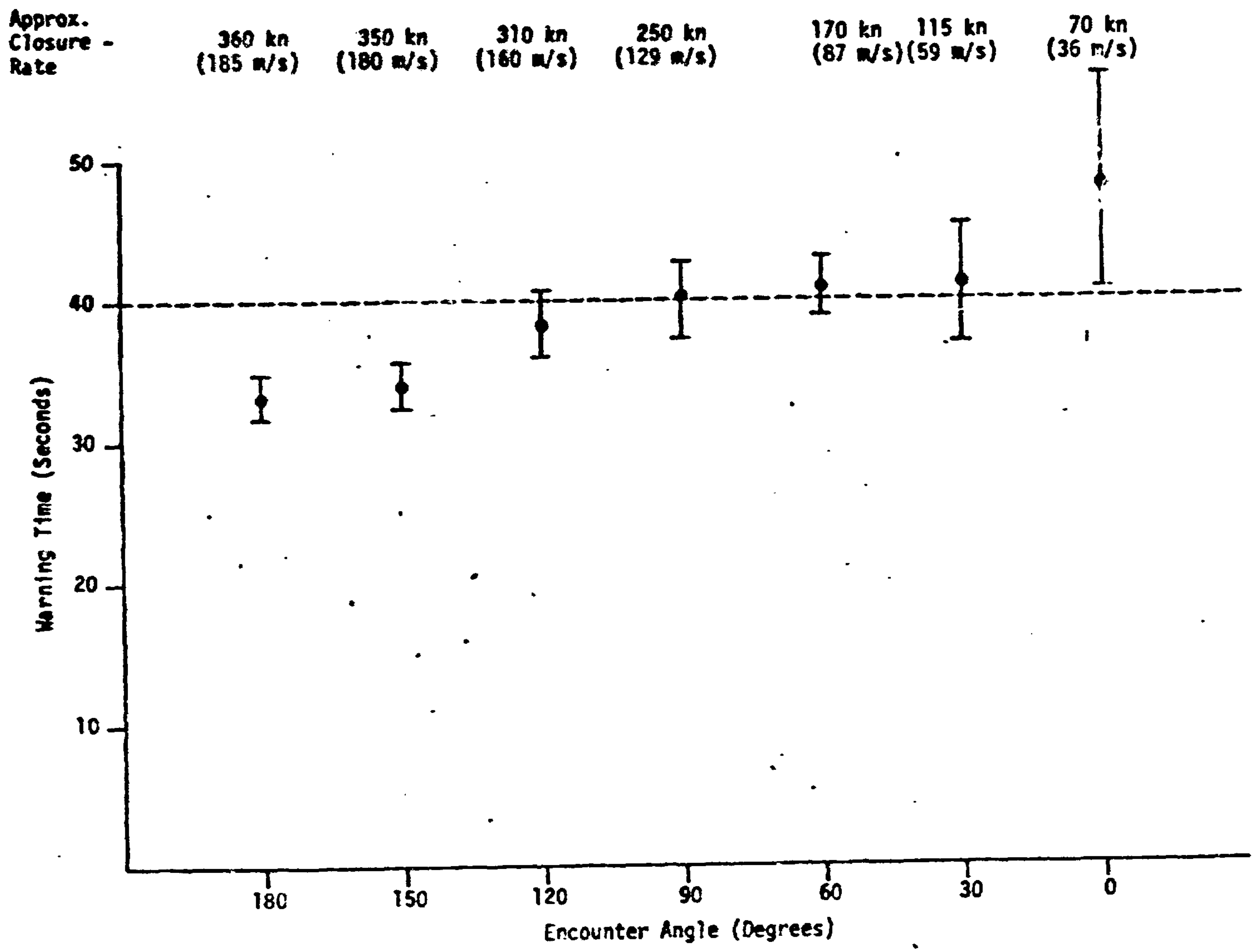


Figure 47. Mean TAU-2 Warning Times Generated by the AVOID II as a Function of Encounter Angle.

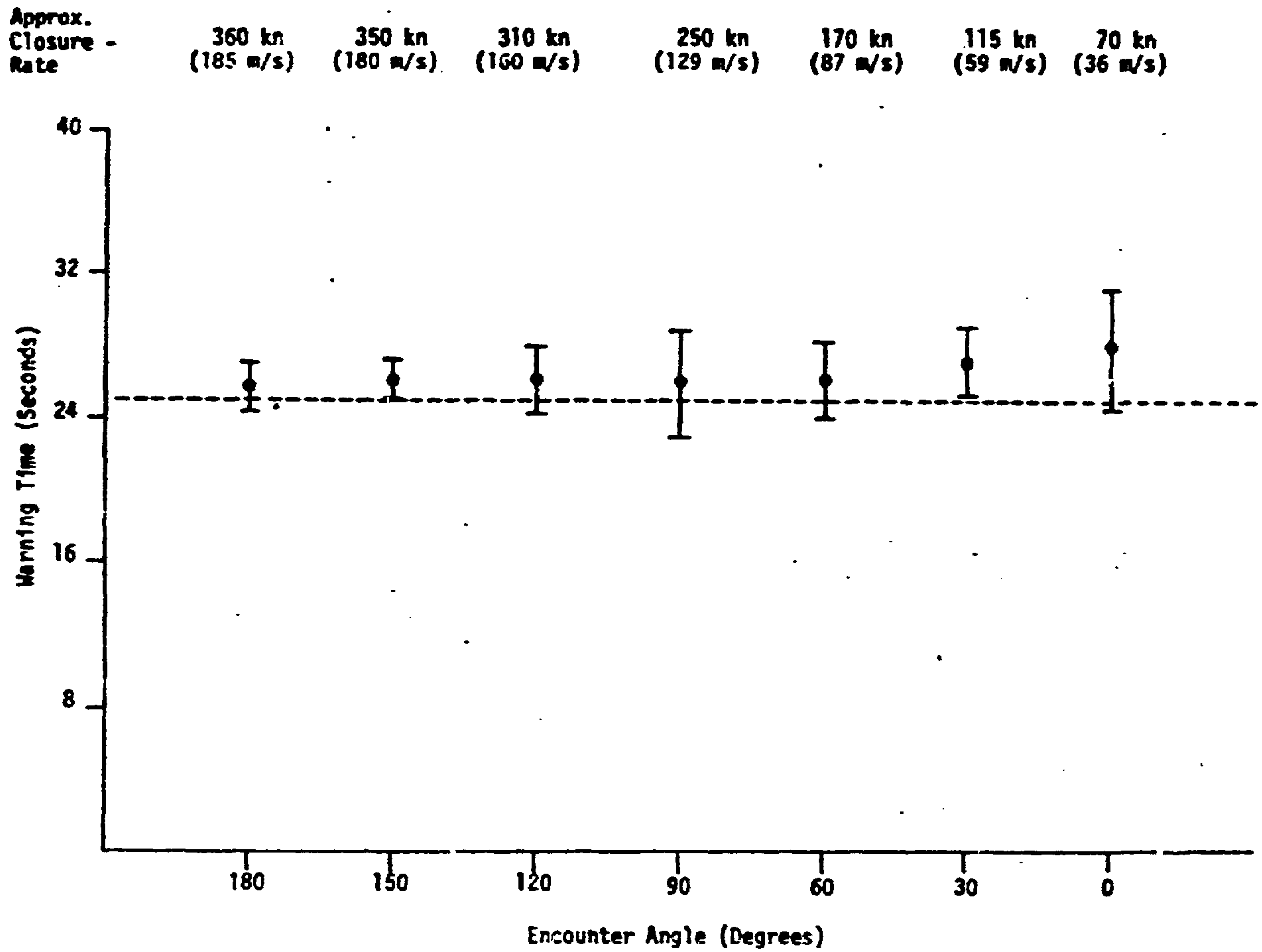


Figure 48. Mean TAU-1 Warning Times Generated by the AVOID II as a Function of Encounter Angle.

The approximate closure rate which occurred during the various encounter angles flown is shown at the top of figures 47 and 48. The reduced Tau-2 warning times which occurred at the 180-degree and 150 encounter angles are not the result of equipment errors but actually the result of the maximum tracking range.

The overall warning times generated during the flight tests are listed in table XXVI. The mean Tau-1 warning time was 26.25 seconds, with a standard deviation of just over 2 seconds. The Tau-2 warning times varied between a mean of 33.34 seconds for the head-on encounters to a mean of 48.19 seconds for the tail chase encounters. The larger standard deviation associated with the tail chase warning times was mainly due to the minimum range threshold which resulted in rapidly increasing warning times for closure rates less than 90 knots (46 m/s). These advisory warning times which vary as a function of closure rate are consistent with the AVOID II system specifications for general aviation requirements.

RANGE AND RANGE RATE ACCURACY

The ratio of measured range divided by range rate is the major criterion used for threat evaluation in the collision avoidance process. This quantity is designated as Tau and is equivalent to the time to collision for nonmaneuvering aircraft on collision courses. The effectiveness of a collision avoidance system is dependent upon its ability to evaluate Tau during flight encounters. Since Tau is a quantity derived from range and range-rate measurements, the accuracy of these measurements determines the true capabilities of the equipment in performing the collision function.

In order to determine the accuracy of the AVOID II measurement of range and range rate, flight encounters were conducted at the NAVAIRTESTCEN (Naval Air Test Center) Chesapeake Theodolite Range. The range consists of six theodolite stations interfaced to a central computer. The encounters flown at the theodolite range involved only the two AVOID II equipped aircraft, with each aircraft being tracked by three theodolites. The optimum resolution of an aircraft's position is achieved when the aircraft's flight path is parallel to a line passing through the six theodolite stations. As a result, the only encounter types flown at the range were of the head-on, the tail chase, or a parallel overtake nature with variations in closure rates. During the encounters, each aircraft's heading and airspeed were monitored by a ground controller to provide the proper encounter closure rate and miss distance.

Data received by the range's central computer from the individual theodolites tracking each aircraft provided a three-theodolite solution for the position of each aircraft. The theodolite data representing the range and range rate between aircraft was smoothed using a five-point moving arc polynomial technique. For the above encounter types, the resultant tracking measurement errors associated with the ground track are 50 feet (1 sigma) (15.2 m) for range between aircraft and 2 knots (1 sigma) (1.03 m/s) for range rate between aircraft.

TABLE XXVI. MEAN TAU-1 AND TAU-2 WAR..NG TIMES PROVIDED DURING AVOID II FLIGHT TESTS

Encounter Angle (deg)	180	150	120	90	60	30	0
TAU-2 (seconds)	33.3 (1.4)	33.9 (1.6)	38.4 (2.4)	40.1 (2.8)	40.9 (2.2)	41.1 (4.4)	48.2 (7.9)
TAU-1 (seconds)	25.8 (1.5)	26.1 (1.1)	26.1 (1.9)	26.1 (3.1)	26.2 (2.1)	27.2 (1.9)	28.0 (3.3)

Note: Standard deviations of times recorded are shown in these parentheses.

As a result of safety of flight considerations, minimum aircraft altitude and range separation were maintained during the flight tests. In an actual collision encounter with zero miss distance, the closure rate is constant up to the point of impact or zero range. However, for the typical small miss distance which occurred during testing, the closure rate changes from a large positive value to a large negative value in a rather short amount of time. The AVOID II was not designed to accommodate such large accelerations, and in addition it is not necessary that a CAS equipment measure such rapidly changing range rates. In order to prevent this transitional phenomena from affecting the evaluation of the AVOID II measurement accuracy, data points corresponding to the transition region during head-on and tail-chase encounters were discarded. In addition, only comparisons of measurements during which each aircraft was being tracked by three theodolites were used in establishing the mean error and its standard deviation. As a result of ground haze, a significant amount of data could not be used due to loss of track by one or more of the six theodolite stations.

The AVOID II stores responses to interrogations in a high-speed shift register. The clock rate of the shift register results in each storage location or bin representing a distance of 50 feet (15.2 m). The range registers are 512 bits long, resulting in a total tracking range of 25,600 feet (4.2 nmi or 7.8 km). After each interrogation, the contents of the high-speed shift register is transferred to lower-speed shift registers for storage. The interrogations occur at 0.5-second intervals during each 3.5-second track cycle. After each interrogation, replies which do not represent possible aircraft trajectories are filtered out. At the end of the track cycle, the range bins are examined for trajectories which represent threatening aircraft. For a trajectory to result, responses within an acceptance window must be received at each 0.5-second interval during the track cycle. The AVOID II evaluates threats on the basis of the number of bins between the responses to the first and last interrogations in the 3.5-second cycle and the range of the first response. That is, the AVOID II does not actually divide the range by the range rate to determine a value for Tau. Associated with each range bin is a minimum number of bins. When this number is exceeded by the number of bins skipped between the first and last interrogation responses, a Tau-2 or Tau-1 threat is identified.

In order to establish AVOID II measurement accuracies the data contained in the range-shift registers is transferred to the digital interface at the end of each 3.5-second track cycle. The digital interface then formats the range in increments of 100 feet (30.5 m), converts the number of bins skipped into range rate in increments of 10 feet per second (305 m/s), and then divides the two quantities to determine the Tau value for that event. The digital interface then transfers the formatted data to the tape recorder.

Significantly, the AVOID II actually assesses the threat status of targets based on 50 foot (15.2 m) range increments while the digital interface allows evaluation of the equipment's range accuracy only to 100 foot (30.5 m) range increments.

All of the encounters flown at the theodolite range were conducted with random pulses representative of the 1982 Los Angeles environment injected at the antenna ports of each AVOID II. These pulses affect the accuracy of measurements since the AVOID II identifies threats based on all possible trajectories. The random pulses do not reduce the magnitude of range rate measurements but can result in the generation of a larger than actual range rate. During a normal track cycle, any trajectory or responses which do not represent a potential threat (ie. a Tau of less than 40 seconds or an aircraft within the minimum range boundary) are discarded. However, in order to allow analysis of the AVOID II operation in all regimes, this feature was disabled during flight tests. For example, range accuracy at a separation of 4 nautical miles could be determined at all range rates rather than only higher range rates which would result in a threatening situation.

Range, range rate, and Tau values provided by the AVOID II were recorded on the digital incremental tape recorder along with the time at which the measurement occurred. The time sources aboard each aircraft as well as the theodolite time were synchronized to the same reference, WWV Boulder, Colorado. In order to compare the AVOID II data with the theodolite data, a four-point Lagrangian interpolation was used to obtain the theodolite derived range and range rate between aircraft at the same instant of time that the AVOID II measurements occurred. The mean error and standard deviation of the AVOID II data from the interpolated theodolite data was then calculated.

Table XXVII is a typical computer printout of AVOID II range, range rate, and Tau measurements and the simultaneous (interpolated) theodolite data. The AVOID II measurements are presented in the first column of each group, the theodolite measurements in the second column of each group, and the difference between the two measurements in the third column. The second part of table XXVII contains the mean, the RMS, and the one sigma values of the range, range rate, and Tau measurement differences. Table XVIII contains similar data relevant to the second aircraft which participated in the encounter.

A total of 20 encounters were flown at the theodolite range, resulting in 524 usable events for data comparison. Table XXIX contains the measurement accuracies achieved by the AVOID II aboard the individual aircraft as well as the overall values.

The mean error of all AVOID II range measurements referenced to the theodolite range measurements was 167 feet (51 m) with a standard deviation of 120 feet (37 m). The mean error of all AVOID II range rate measurements referenced to the theodolite range rate measurements was 6.6 knots (3.4 m/s) with a standard deviation of 6.6 knots (3.4 m/s).

TABLE XXVII. RANGE, RANGE RATE, AND TAU DATA FOR THEODOLITE RANGE ENCOUNTER (P-3A)

AIRCRAFT- NC-117 PRINTOUT OF RANGE AND RANGE RATE TO P-3A
FLIGHT NO. 10
ENCOUNTER NO. 14

TIME			RANGE			RANGE RATE			TAU		
H	M	SEC	A/C (NMI)	THEO (NMI)	DIFF (NMI)	A/C (KNTS)	THEO (KNTS)	DIFF (KNTS)	A/C (SEC)	THEO (SEC)	DIFF (SEC)
14	50	9.071	3.3900	3.3202	0.0698	71.000	49.963	21.037	171.89	239.26	-67.37
14	50	17.318	3.2920	3.2262	0.0698	53.000	43.640	9.360	223.61	265.91	-42.30
14	50	21.059	3.2826	3.1768	0.0671	41.000	41.874	-0.874	284.60	272.90	11.70
14	50	24.807	3.1930	3.1249	0.0681	53.000	42.196	10.804	216.88	260.61	-43.73
14	50	28.443	3.1439	3.0838	0.0592	67.000	61.672	5.328	240.70	266.41	-25.67
14	50	32.312	3.1113	3.0378	0.0735	35.000	47.465	-12.465	319.99	230.41	89.58
14	50	36.192	3.0450	2.9863	0.0587	53.000	51.030	1.970	230.53	210.67	-3.84
14	50	39.991	2.9955	2.9367	0.0583	65.000	46.814	18.186	165.88	225.83	-59.96
14	50	43.598	2.9450	2.8809	0.0651	53.000	53.968	-0.968	200.11	192.10	8.00
14	50	47.456	2.9400	2.8204	0.0596	59.000	58.470	0.530	175.73	173.65	2.37
14	50	51.279	2.8140	2.7578	0.0562	71.000	61.010	9.990	142.68	162.73	-20.05
14	50	55.120	2.7480	2.6924	0.0552	65.000	62.312	2.688	152.20	155.57	-3.33
14	50	58.929	2.6830	2.6295	0.0535	71.000	60.812	10.188	138.04	159.60	-19.02
14	51	2.571	2.6170	2.5640	0.0530	71.000	64.656	6.344	132.69	142.76	-10.07
14	51	6.499	2.5510	2.4965	0.0545	71.000	61.693	9.307	129.35	145.89	-16.54
14	51	10.249	2.4690	2.4283	0.0407	71.000	65.504	5.496	125.19	133.45	-8.27
14	51	14.335	2.4030	2.3611	0.0419	71.000	62.370	8.630	121.34	136.20	-14.86
14	51	17.916	2.3370	2.2909	0.0461	71.000	64.968	6.032	116.53	120.34	-6.45
14	51	21.957	2.2710	2.2222	0.0488	71.000	67.191	3.809	115.15	119.96	-3.81
14	51	25.342	2.1890	2.1519	0.0371	71.000	65.856	5.144	113.99	117.83	-3.84
14	51	29.335	2.1236	2.0818	0.0418	71.000	65.511	5.489	107.65	110.40	-2.76
14	51	33.387	2.0570	2.0138	0.0432	71.000	68.344	2.656	104.30	105.70	-1.40
14	51	36.844	1.9750	1.9438	0.0311	77.000	65.575	11.425	92.38	106.72	-14.35
14	51	40.339	1.9090	1.8742	0.0348	71.000	65.546	5.454	90.79	102.93	-6.14
14	51	44.425	1.8430	1.8026	0.0404	71.000	68.649	2.351	93.45	94.53	-1.08
14	51	48.120	1.7610	1.7339	0.0271	77.000	66.549	10.451	82.33	93.79	-11.46
14	51	51.957	1.6950	1.6651	0.0299	71.000	59.691	11.309	85.94	100.42	-14.48
14	51	55.999	1.6459	1.6064	0.0394	53.000	52.025	0.975	111.90	111.10	0.80
14	51	59.995	1.5959	1.5598	0.0379	53.000	38.933	14.066	108.41	144.12	-35.71
14	52	3.392	1.5430	1.5196	0.0434	35.000	34.343	0.657	150.77	149.20	1.57
14	52	7.245	1.5189	1.4843	0.0297	35.000	34.778	0.222	153.73	151.63	2.09
14	52	10.942	1.4810	1.4491	0.0319	35.000	34.002	0.998	152.33	153.42	-1.09
14	52	14.847	1.4480	1.4143	0.0337	35.000	33.654	1.346	148.94	151.29	-2.35
14	52	18.556	1.4150	1.3793	0.0357	35.000	32.593	2.407	145.54	152.34	-6.80
14	52	22.392	1.3820	1.3449	0.0371	41.000	28.819	12.181	121.35	168.00	-46.65
14	52	26.331	1.3500	1.3187	0.0313	23.000	25.736	-2.736	211.30	184.80	26.50
14	52	29.844	1.3170	1.2930	0.0276	35.000	24.170	10.830	135.46	192.13	-56.67
14	52	33.727	1.3030	1.2662	0.0368	29.000	24.570	4.430	161.38	185.08	-23.70
14	52	37.477	1.2670	1.2350	0.0280	29.000	23.492	5.508	157.28	189.67	-32.39
14	52	41.179	1.2510	1.2140	0.0370	23.000	22.193	0.807	185.81	186.92	-1.11
14	52	45.015	1.2180	1.1942	0.0238	17.000	15.488	1.512	257.93	277.58	-19.65
14	52	48.814	1.2010	1.1739	0.0271	17.000	18.034	-1.034	254.33	234.34	19.99
14	52	52.646	1.1850	1.1596	0.0254	17.000	8.842	8.158	250.04	472.12	-221.18
14	52	56.466	1.1850	1.1543	0.0307	11.000	7.028	3.972	387.82	591.25	-203.44
14	53	0.497	1.1855	1.1480	0.0370	0.000	3.174	-3.174	0.00	1301.85	-1301.85
14	53	4.191	1.1850	1.1489	0.0361	0.000	-3.460	3.460	0.00	-1188.45	1188.45
14	53	9.329	1.1950	1.1488	0.0462	0.000	0.190	-0.190	0.00	20768.53	********
14	53	11.027	1.1850	1.1539	0.0311	-11.000	-4.139	-6.861	-387.82	-1003.77	615.95

* PRUIT

AIRCRAFT- NC-117 PRINTOUT OF RANGE AND RANGE RATE TO P-3A
FLIGHT NO. 10
ENCOUNTER NO. 14

RANGE			RANGE RATE			TAU		
POINTS	49		POINTS	48		POINTS	48	
MEAN	0.0411 NM	251.22 FT	MEAN	6.7352 KTS		MEAN	-441.68 SECS	
RMS	0.0454 NM	276.35 FT	RMS	7.6500 KTS		RMS	3014.91 SECS	
SIGMA	0.0139 NM	84.56 FT	SIGMA	6.3631 KTS		SIGMA	3013.53 SECS	

TABLE XXVIII. RANGE, RANGE RATE, AND TAU DATA FOR THEODOLITE RANGE ENCOUNTER (NC-117)

AIRCRAFT- P3A PRINTOUT OF RANGE AND RANGE RATE TO NC-117
FLIGHT NO. 18
ENCOUNTER NO. 14

TIME H M SEC	RANGE A/C (NMI)	RANGE THEOD (NMI)	RANGE DIFF (NMI)	RANGE RATE A/C (KNTS)	RANGE RATE THEOD (KNTS)	RANGE RATE DIFF (KNTS)	TAU A/C (SEC)	TAU THEOD (SEC)	TAU DIFF (SEC)
14 50 13.287	3.3410	3.2683	0.0727	59.000	51.736	7.294	203.80	227.50	-23.70
14 50 17.396	3.2920	3.2213	0.0707	53.000	43.852	9.148	223.41	264.45	-41.04
14 50 22.026	3.2420	3.1743	0.0677	53.000	42.044	10.956	220.21	271.80	-51.59
14 50 26.797	3.1750	3.1237	0.0523	59.000	41.751	17.249	193.79	269.34	-75.55
14 50 30.553	3.1435	3.0820	0.0610	47.000	41.591	5.409	240.74	266.77	-26.03
14 50 32.793	3.0940	3.0380	0.0560	59.000	47.449	11.551	188.79	230.49	-41.70
14 50 36.306	3.0450	2.9874	0.0577	53.000	50.900	2.100	200.83	211.28	-10.45
14 50 38.737	2.9953	2.9376	0.0577	59.000	46.604	12.396	182.75	228.94	-46.19
14 50 41.722	2.9300	2.8805	0.0495	53.000	53.976	-0.976	199.02	192.12	6.90
14 50 47.519	2.8580	2.8134	0.0446	71.000	58.465	12.535	145.22	173.41	-28.19
14 50 51.355	2.8140	2.7559	0.0581	59.000	61.036	-2.036	171.70	162.55	9.15
14 50 55.253	2.7350	2.6938	0.0412	71.000	62.283	8.717	138.52	155.53	-17.01
14 50 59.154	2.6660	2.6238	0.0422	71.000	61.326	9.674	135.10	154.03	-18.93
14 51 2.951	2.5990	2.5571	0.0420	71.000	64.813	6.187	131.83	142.02	-10.19
14 51 8.812	2.5050	2.4597	0.0453	71.000	61.649	9.351	128.54	143.39	-14.85
14 51 12.579	2.4690	2.4223	0.0467	71.000	65.526	5.474	125.10	133.08	-7.98
14 51 14.034	2.4030	2.3549	0.0481	71.000	63.033	7.967	121.65	134.50	-12.85
14 51 18.211	2.3010	2.2656	0.0357	71.000	64.793	6.207	117.68	127.30	-9.62
14 51 22.398	2.2550	2.2149	0.0401	71.000	66.439	4.561	114.34	120.04	-5.70
14 51 25.334	2.1830	2.1403	0.0427	71.000	66.363	4.637	110.09	115.53	-5.44
14 51 29.714	2.1250	2.0795	0.0455	71.000	65.262	5.738	107.45	114.41	-6.96
14 51 33.833	2.0680	2.0324	0.0356	71.000	67.881	3.119	103.49	106.19	-2.70
14 51 37.741	1.9580	1.9302	0.0278	82.000	67.981	14.019	85.96	102.22	-16.26
14 51 41.812	1.9490	1.9007	0.0483	65.000	64.665	0.335	105.73	103.54	2.19
14 51 43.472	1.8370	1.7963	0.0407	77.000	68.036	8.964	85.42	94.54	-9.12
14 51 48.076	1.7450	1.7174	0.0276	82.000	66.048	15.952	76.01	93.34	-17.33
14 51 52.827	1.6790	1.6506	0.0284	71.000	57.754	13.246	85.13	102.88	-17.75
14 51 55.038	1.6290	1.5933	0.0357	59.000	48.878	10.122	99.40	117.35	-17.95
14 52 2.445	1.5800	1.5495	0.0305	41.000	38.180	2.820	138.73	146.10	-7.37
14 52 4.105	1.5466	1.5122	0.0344	47.000	33.454	13.546	118.49	162.72	-44.23
14 52 [illegible]	1.5140	1.4773	0.0367	35.000	34.675	0.325	155.73	153.38	2.35
14 52 11.795	1.4810	1.4414	0.0396	35.000	33.528	1.472	152.33	154.77	-2.44
14 52 15.992	1.4320	1.4043	0.0277	35.000	33.334	1.666	147.23	151.69	-4.46
14 52 18.421	1.3990	1.3714	0.0275	41.000	33.466	7.534	122.94	147.52	-24.58
14 52 23.184	1.3660	1.3391	0.0270	29.000	27.942	1.058	169.57	172.39	-2.82
14 52 27.231	1.3533	1.3116	[illegible]	29.000	26.890	2.110	167.59	175.59	-8.00
14 52 30.593	1.3170	1.2832	0.0338	29.000	23.796	5.204	163.49	194.14	-30.65
14 52 34.513	1.2840	1.2575	0.0265	23.000	24.540	-1.540	200.97	184.47	16.50
14 52 38.176	1.2670	1.2334	0.0336	29.000	23.936	5.064	157.28	185.50	-28.22
14 52 42.242	1.2640	1.2378	0.0262	29.000	20.140	8.860	153.19	215.90	-62.71
14 52 45.261	1.2180	1.1902	0.0278	17.000	17.443	-0.443	257.93	245.64	12.29
14 52 49.203	1.2040	1.1734	0.0306	29.000	15.227	13.773	149.09	276.73	-127.64
14 52 52.083	1.1850	1.1584	0.0266	11.000	4.868	6.132	357.82	854.40	-496.58
14 52 57.457	1.1850	1.1523	0.0327	11.000	7.450	3.550	357.82	550.78	-192.96
14 53 1.431	1.0530	1.1474	-0.0944	11.000	1.368	9.632	344.62	3318.86	-2974.24
14 53 4.983	1.1880	1.1531	0.0349	-11.000	-2.234	-8.766	-357.82	-1853.73	1495.91
14 53 0.946	1.1840	1.1491	0.0350	0.000	-3.485	3.485	0.00	-1187.06	1187.06

* FRGIT

AIRCRAFT- P3A PRINTOUT OF RANGE AND RANGE RATE TO NC-117
FLIGHT NO. 18
ENCOUNTER NO. 14

RANGE	RANGE RATE	TAU
POINTS 47	POINTS 47	POINTS 47
MEAN 0.0384 NM 233.20 FT	MEAN 6.2537 KTS	MEAN -31.51 SECS
RMS 0.0448 NM 272.01 FT	RMS 8.2104 KTS	RMS 463.82 SECS
SIGMA 0.0233 NM 141.44 FT	SIGMA 5.3510 KTS	SIGMA 455.01 SECS

TABLE XXIX. RANGE AND RANGE RATE ERROR STATISTICS

Group	Data Sample N	Range Error Mean	Range Error Sigma	Range Rate Error Mean	Range Rate Error Sigma
NC-117	267	174 ft (53 m)	107 ft (33 m)	6.2 kn (3.2 m/s)	6.6 kn (3.4 m/s)
P-3A	257	159 ft (48 m)	132 ft (40 m)	7.1 kn (3.7 m/s)	6.6 kn (3.4 m/s)
P-3A & NC-117	524	167 ft (51 m)	120 ft (37 m)	6.6 kn (3.4 m/s)	6.6 kn (3.4 m/s)

BIBLIOGRAPHY

1. Honeywell Proposal E7417-RD of 31 May 1974 consisting of:
   a. Technical Description AVOID II, E7417-RD
   b. Modification of E7417 of 10 July 1974

2. AVOID I Specification HRS 24707-01 of 28 December 1973.

3. AVOID Digital Display and Interface Specifications HRS 24709-01 of 17 December 1973.

4. AVOID Traffic Simulator Specification HRS 24708-01 of 17 December 1973.

APPENDIX A

HONEYWELL CUSTOMER ENGINEERING LETTER OF 26 DECEMBER 1974

AVOID INTERROGATION AND FRUIT RATES

CUSTOMER ENGINEERING LETTER

James J. Bagnall, Jr.
Science and Technology Division
Institute For Defense Analysis
400 Army-Navy Drive
Arlington, Virginia 22202

Subject: AVOID INTERROGATION AND FRUIT RATES

SUMMARY

Honeywell Inc. has conducted a study to determine the interrogation and fruit rates expected in the L.A. Basin in 1982.

The baseline air traffic model used was Snapshot 1 as given in the Mitre Corporation Report[1]. Snapshot 1 contains 743 aircraft. Calculations normalized to 800 aircraft are also included.

The basic analytic approach was to treat each aircraft in the model on an individual basis. The computer was used extensively due to the large number of calculations involved.

All IFR aircraft were assumed to be equipped with the AVOID-I CAS (ANTC-117 threat criteria).

VFR aircraft were assumed to be equipped with the AVOID-II CAS that is to be delivered to NADC[2]. The AVOID-II is designed for General Aviation aircraft that operate under 10,000 feet.

The resulting mix of CAS equipment is approximately 15 percent AVOID-I and 85 percent AVOID-II.

The expected fruit rates over the LA terminal and at a point 15 miles east and 10 miles south of the terminal were calculated. The latter position is at the approximate center of the most dense air traffic.

Average interrogation rates (transmitted and received) for the AVOID-I and AVOID-II were also calculated.

From the received fruit and interrogation rates the transponder blockage and the false alarm rates for the AVOID-I and AVOID-II were estimated.

The results of these calculations are summarized on page two.

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[1] "Statistical Summary of the 1982 Los Angeles Bsin Standard Traffic Model", April 1973, MTR-6387.

[2] RFP N62269-74-R-0674.

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GOVERNMENT & AERONAUTICAL
PRODUCTS DIVISION
MINNEAPOLIS OPERATIONS

NADC-76141-60

C.E.L. NO.

DATE December 26, 1974

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[1] "Statistical Summary of the 1982 Los Angeles Bsin Standard Traffic Model", April 1973, MTR-6387.

[2] RFP N62269-74-R-0674.

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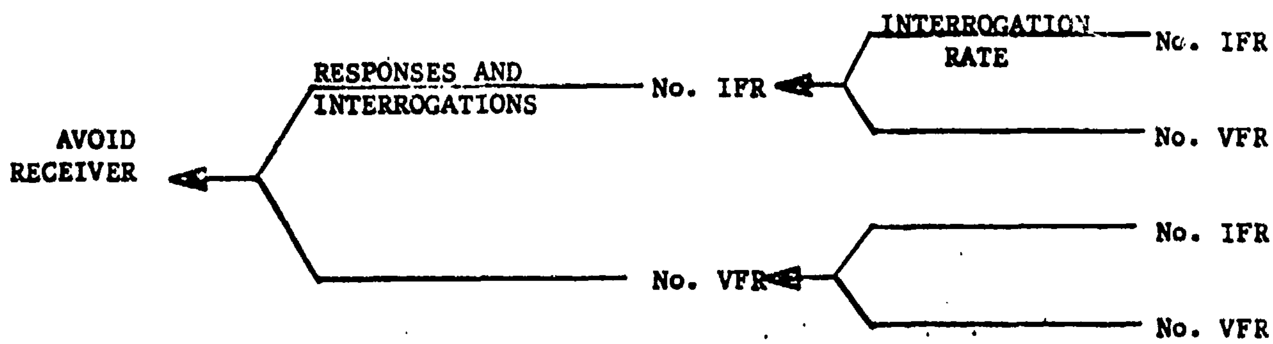
SUMMATION OF RESULTS[1]

	AVOID-I	AVOID-II
Average Interrogations Transmitted per second	11.0	9.4
Average Interrogations Received per second	2158	1240
Fruit Pulses Received per second	78,715	47,592
Probability of Response (single Interrogation)	0.92815	0.96000
Probability of Response (one or more of three interrogations)	0.99963	0.999936
Probability of Detecting Threat (First Set)	[2] 0.983	[3] 0.995
Probability of Detecting Threat (Remaining Sets)	[2] 0.997	[3] 0.9995
Probability of False Alarm (per altitude band per sequence)	6.325×10^{-8}	7.12×10^{-11}
Hours per False Alarm (all bands)	8000	7.2×10^{6}
Hours per False Alarm (coaltitude)	1.3×10^{6}	1.2×10^{9}

Notes:
1) These results are based on an aircraft at an altitude of 5000 feet in the highest density region of the L.A. Basin with the loop sensitivity 2 db above nominal.
2) The probability of an AVOID-I or an AVOID-II detecting an AVOID-I.
3) The probability of an AVOID-I or an AVOID-II detecting an AVOID-II.

A. INTRODUCTION

The average fruit rate received by an AVOID receiver can be estimated if the interrogation and response rates of all aircraft within communication range are known. The following figure identifies the parameters that must be determined.



The AVOID receiver under question receives responses and interrogations from a given number of IFR and VFR aircraft (AVOID-I and AVOID-II). The number of fruit pulses transmitted by each aircraft is determined by the number of interrogations each receives. This is stated in equation form below:

AVOID-I FRUIT EQUATION

(NO. AVOID-I RESPONDERS) (AVERAGE NO. AVOID-I INTERROGATORS) $\frac{R_1}{5}$

+(NO. AVOID-I RESPONDERS) (AVERAGE NO. AVOID-II INTERROGATORS) $\frac{R_2}{5}$

+(NO. AVOID-II RESPONDERS) (AVERAGE NO. AVOID-I INTERROGATORS) $\frac{R_1}{5}$

+(NO. AVOID-II RESPONDERS) (AVERAGE NO. AVOID-II INTERROGATORS) $\frac{R_2}{5}$

+(NO. AVOID-I) $4R_1$ + (NO. AVOID-II) $4R_2$

The last two terms in the equation account for interrogations received during the "listening period" by the receiver for which fruit is being calculated.

/Cont'd. . .

The R_1 and R_2 terms are the average interrogation rates of the AVOID-I and AVOID-II respectively. The interrogation rates are divided by 5 due to the altitude descrimination utilized in the system which allows it to respond to only approximately 1/5 of the interrogations received.

B. AVERAGE TRANSMITTED INTERROGATION RATES

The interrogation rate depends on the interrogation decision logic and threat status. A computer program was written to determine the threat status of each aircraft in Snapshot 1.

The programmed threat criteria for all IFR aircraft was similar to ANTC-117 requirements. The threat criteria, altitude bands and interrogation schedule for all IFR aircraft are given in figures 1, 2, and 3 respectively.

The threat criteria, altitude bands and interrogation schedule for all General Aviation aircraft (VFR) is given in figures 4, 5, and 6 respectively.

It was assumed all aircraft interrogated the first three sets with the remaining sets interrogated only if a threat occurred in the interrogated band. The required interrogations for the AVOID-I (IFR) with a threat is shown in Figure 3 and for the AVOID-II (VFR) with a threat in Figure 6. In these two figures a "T" indicates a tau threat and "H" an altitude correlation. The interrogation decision logic used assumed an aircraft was not in violation of a displayed advisory. For example, if a limit climb to less than 500 fpm advisory was displayed it was assumed the climb rate "H" was less than 500 fpm and therefore the +15 and +26 interrogations were not made.

AVOID-I

	Number of Aircraft	Total Interrogations (3.7 sec)
IFR WITH NO THREATS	53	732
IFR WITH ONE OR MORE THREATS	60	3852
	113	4584

AVERAGE INTERROGATION RATE PER SECOND

$$= \frac{4584}{113(3.7)} = 11.0$$

This interrogation rate was assumed for all IFR aircraft in subsequent calculations.

A similar correlation of threat status and interrogation decision logic for the 630 VFR aircraft was completed. The results are tabulated below:

AVOID-II

	Number of Aircraft	Total Interrogations (3.7 sec)
VFR WITH NO THREATS	356	4272
VFR WITH ONE OR MORE THREATS	274	17640
	630	21912

AVERAGE INTERROGATION RATE PER SECOND $= \frac{21,912}{630(3.7)} = 9.4$

This interrogation rate was assumed for all VFR aircraft in subsequent calculations.

C. AVERAGE COMMUNICATION RANGES

The baseline AVOID power and sensitivity are summarized below:

AVOID POWER BUDGET SUMMARY (BASELINE DESIGN)

	POWER TRANSMITTED(EACH ANT.)	RECEIVER SENSITIVITY
AVOID-I	58dBm	-71dBm
AVOID-II	55dBm	-68dBm

The power budget was[3] chosen to obtain near equal gain margins for all communication links. The baseline communication link parameters are listed below:

XMITTER	RECEIVER	REQUIRED RANGE(FT)	PATH LOSS(dB)	LOOP SENSITIVITY(dB)	GAIN MARGIN(dB)	AVG.COMM. RANGE(mi)
AVOID-I	AVOID-I	52,800	121	129	8.0	17
AVOID-I	AVOID-II	43,500	119.5	126	6.5	12
AVOID-II	AVOID-I	43,500	119.5	126	6.5	12
AVOID-II	AVOID-II	25,600	115.0	123	8.0	8.[illegible]

By increasing the transmitted power of each AVOID transmitter (each antenna) by 2dB the average communication range increases to the values given in the following table:

COMMUNICATION LINK PARAMETERS (+2dB)

XMITTER	RECEIVER	REQUIRED RANGE(FT)	PATH LOSS(dB)	LOOP SENSITIVITY(dB)	GAIN MARGIN(dB)	AVG.COMM. RANGE(mi)
AVOID-I	AVOID-I	52,800	121	131	10.0	21.4
AVOID-I	AVOID-II	43,500	119.5	128	8.5	15.1
AVOID-II	AVOID-I	43,500	119.5	128	8.5	15.1
AVOID-II	AVOID-II	25,600	115.0	125	10.0	10.6

[3] The AVOID-I flight test models have the same loop sensitivity (transmitted power = 55dBm, Receiver sensitivity = -74dBm)

The IDA[4] report estimated that the average communication range between two AVOID-I systems with 129dBm loop sensitivity to be 17nmi when using the antenna patterns of a Boeing 737 which has a forward gain of 3dB. The same report estimated that communication range between two AVOID-II systems with 126dBm loop sensitivity and omnidirectional antenna patterns to be 12 nmi. Since the baseline AVOID-II loop sensitivity is 123dBm (required range was reduced to 25,600 ft), the average communication range between two AVOID-II systems is 8.4nmi.

The AVOID-I to AVOID-II communication range was estimated by Honeywell to be 12nmi (loop sensitivity of 126dB). This assumes omnidirectional antenna patterns on both aircraft.

D. AVERAGE FRUIT AND INTERROGATIONS RECEIVED

A computer program was written to determine the number of aircraft (snapshot 1) in communication given the communication ranges listed in Section C. The program was modified twice as shown below:

CENTER	COMM. RANGE
LA TERMINAL	BASELINE
15 MI EAST, 10 MI SOUTH	BASELINE
15 MI EAST, 10 MI SOUTH	+2dB to LOOP SEN.

The number of aircraft in communication, the fruit received and the interrogations received is summarized on pages 6, 7, 8, and 9. A sample calculation is given below:

SAMPLE CALCULATION OF AVOID-I FRUIT AND INTERROGATION RATE

[RESPONSES RECEIVED (15 MILES EAST, 10 MILES SOUTH)]

$1/5[25(24)(11.0) + 25(91)(9.4) + 120(13)(11.0) + 120(55)(9.4)]$

Responses Received = 21,437

INTERROGATIONS RECEIVED

$25(11.0) + 120(9.4) = 1403$

TOTAL FRUIT RECEIVED

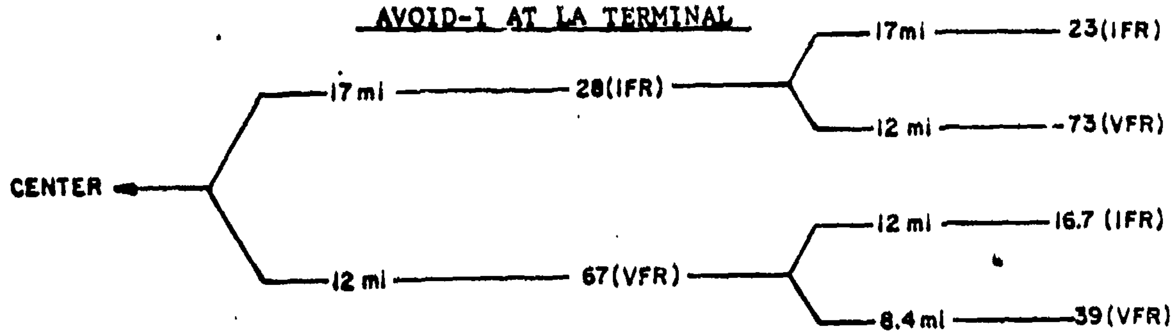
$[21,437 + 4(1403)]\ 1.3 = 35,164$ Fruit Pulses/Sec.

/Cont...

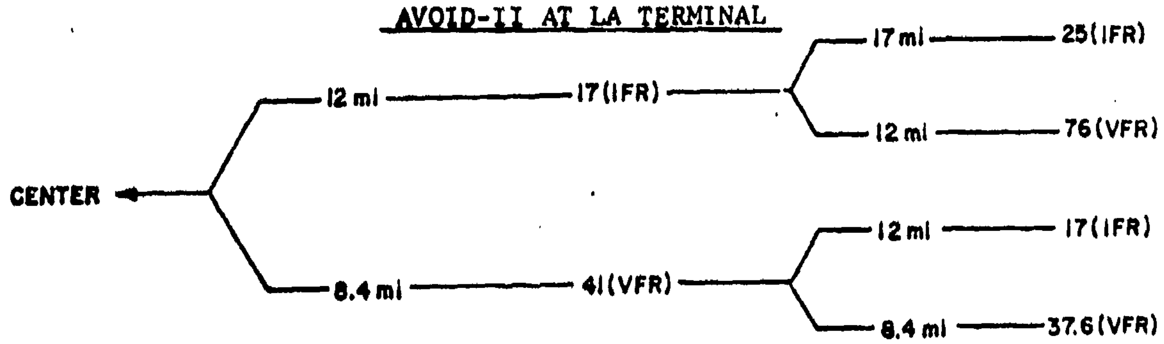
[4] "A review and analysis of the Honeywell Collision Avoidance System", IDA Study S-424 Oct. 1973.

NUMBER OF AIRCRAFT IN COMMUNICATION

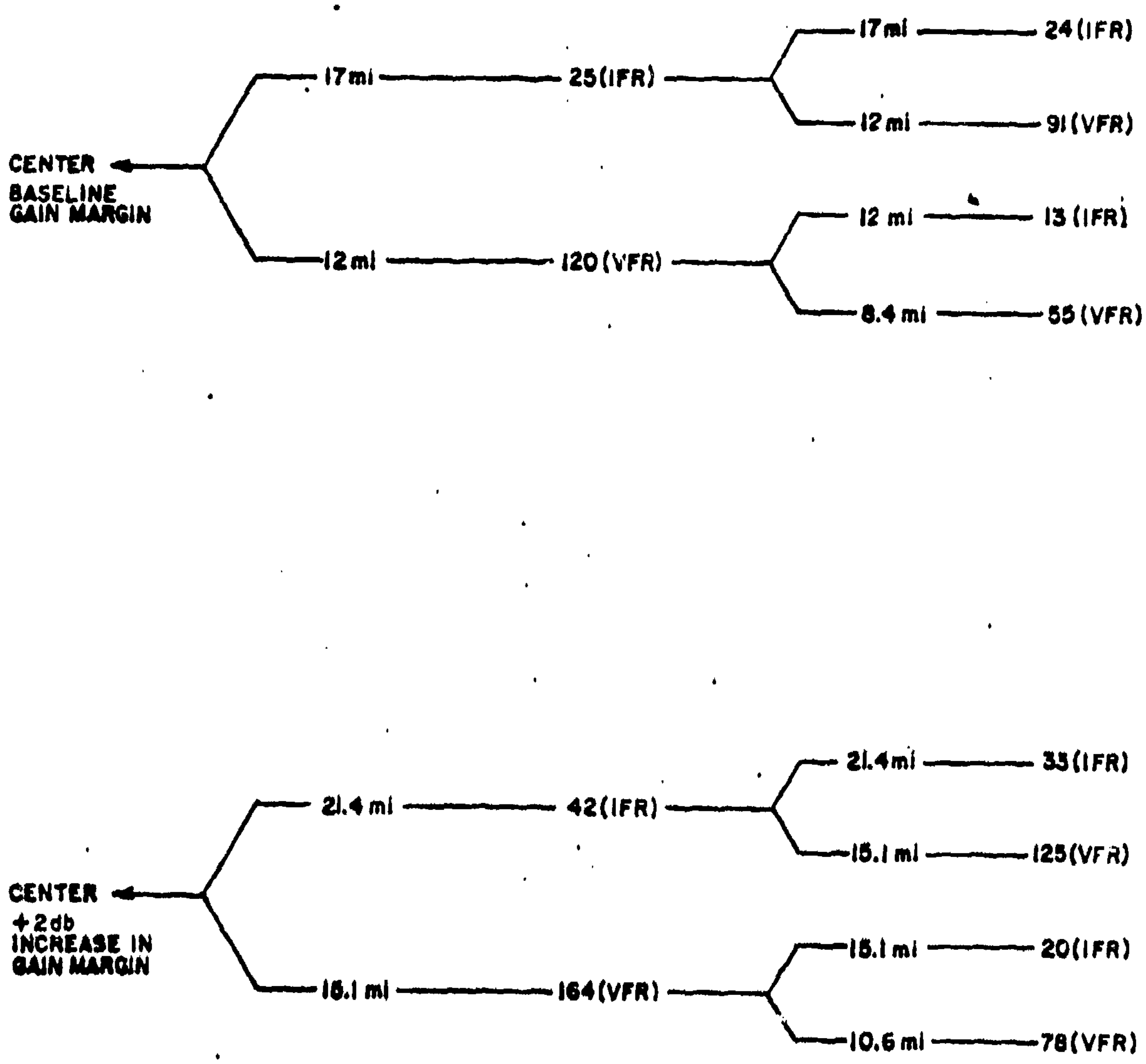
AVOID-I AT LA TERMINAL



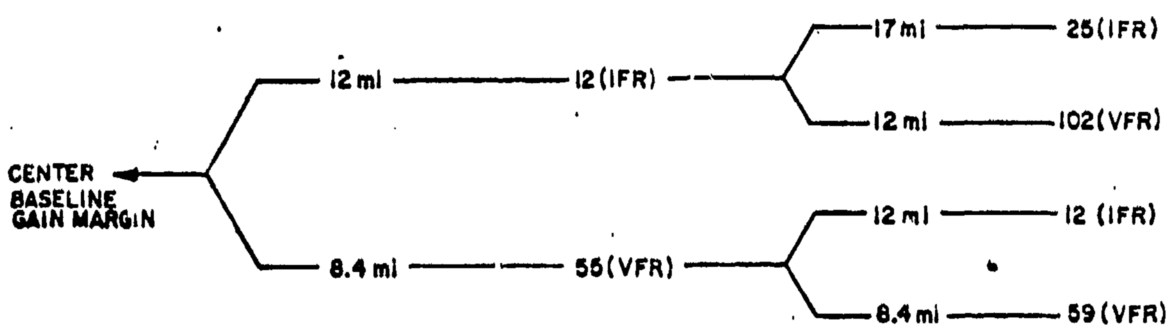
AVOID-II AT LA TERMINAL

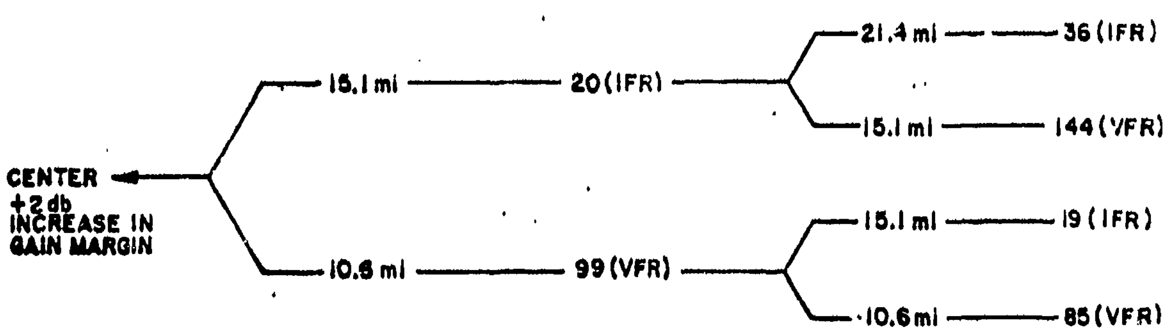


AVOID-I AT 15 MI EAST, 10 MI SOUTH



AVOID-II AT 15 MI EAST, 10 MI SOUTH





SUMMATION OF FRUIT AND INTERROGATIONS RECEIVED

CAS	CENTER	POWER BUDGET	INTERROGATIONS RECEIVED	RESPONSES RECEIVED	TOTAL PULSES REC.	TOTAL FRUIT INCL. MULTIPATH	FRUIT NORMAL TO 800 A/C.
AVOID-I	LA BASIN	BASELINE	938	12,634	16,386	21,302	24,710
AVOID-I	EAST 15 SOUTH 10	BASELINE	1403	21,437	27,049	35,164	40,790
AVOID-I	EAST 15 SOUTH 10	+2dB	2004	44,184	52,198	67,858	78,715
AVOID-II	LA BASIN	BASELINE	572	7,796	10,084	13,109	15,207
AVOID-II	EAST 15 SOUTH 10	BASELINE	649	10,514	13,110	17,043	19,770
AVOID-II	EAST 15 SOUTH 10	+2dB	1151	26,957	31,559	41,027	47,592

The interrogations received are multiplied by 4 because each interrogation contains 4 pulses. The 1.3 factor accounts for an average multipath reception rate of 30 percent. The 1/5 factor is included because only approximately 1/5 of the interrogations received require a reply.

The increased loop sensitivity of AVOID-I's operating above 10,000 feet (+4dB transmitter power) from each antenna was not included in the calculation of number of aircraft in communication. These aircraft will require very few responses that contribute to fruit.

E. TRANSPONDER BLOCKAGE

The maximum interrogation received rate occurs 15 miles east and 10 miles south of the L.A. center. At this location, with +2dB added to the loop sensitivity, the AVOID-I receives 2004 interrogations per second and the AVOID-II receives 1151 interrogations per second. If the assumed number of aircraft is 800 in place of the 743 aircraft in the model the interrogation received rate is increased by a factor of 800/743 resulting in 2158 interrogations per second received by the AVOID-I and 1240 interrogations per second received by the AVOID-II. Of the interrogations received 30 percent will have an associated multipath signal and 20 percent will require the AVOID system to respond. The received interrogations can thus be divided into the following categories.

AVOID-I	AVOID-II	Category
1209	694	Response not required, No multipath received
518	298	Response not required, Multipath signal received
302	174	Response required, No multipath received
129	74	Response required, Multipath signal received
2158	1240	Total

With no response required and no multipath signal the second response channel is blocked for a maximum of 16 microseconds. With no response required and multipath blocking the second channel the processor is blocked for a total of 46.3 microseconds, for an aircraft at an altitude of 5000 feet. With a response required and no multipath signal the second channel is blocked for 16 microseconds and, when the response is transmitted, both channels are blocked for an additional 3 microseconds. With a response required and multipath the transponder is blocked until 3 microseconds after the response is transmitted or 70.6 microseconds for an altitude of 5000 feet. The approximate AVOID-I and AVOID-II blockage from received interrogations is thus:

AVOID-I	AVOID-II
$1209 \times 16.0 \times 10^{-6} = .01934$	$694 \times 16.0 \times 10^{-6} = .01110$
$518 \times 46.3 \times 10^{-6} = .02398$	$298 \times 46.3 \times 10^{-6} = .01380$
$302 \times 19 \times 10^{-6} = .00574$	$174 \times 19.0 \times 10^{-6} = .00331$
$129 \times 70.6 \times 10^{-6} = .00911$	$74 \times 70.6 \times 10^{-6} = .00522$
Total .05817 sec/sec	.03343 sec/sec

In addition to the interrogations received the AVOID-I receives 44,184 responses per second and the AVOID-II receives 26,957 responses per second

in the 743 aircraft environment. For 800 aircraft and assuming 30 percent multipath these numbers would be increased by a factor of $(800/743)^2$ X 1.3 resulting in 66,590 responses per second received by the AVOID-I and 40,628 responses per second received by the AVOID-II. The pulse pair decoders have a 100 nanosecond gate therefore the AVOID-I will decode approximately $(66,590)^2$X100 X 10^{-9} = 165 responses per second as interrogations. Each response decoded as an interrogation will block the system for 16 microseconds. For the AVOID-I this will result in a blockage of 443 X 16.0 X 10^{-6} = .00709 sec/sec and the AVOID-II will be blocked for approximately 165 X 16.0 X 10^{-6} = .00264 sec/sec.

The maximum transmitted interrogation rate is 156 interrogations per 3.7 seconds for the AVOID-I or 42 interrogations per second. For the AVOID-II the maximum transmitted interrogation rate is 93 interrogations per 3.7 seconds or 25 interrogations per second. A transmitted interrogation blocks the response circuits from transmission of the first pulse until 112 microseconds after the last pulse is transmitted. For an aircraft at 5000 feet this blockage is [32.6 + 12.4 + 112.0] = 157.0 microsecond per interrogation or for the AVOID-I .00659 sec/sec and .00393 sec/sec for the AVOID-II. The total possible blockage, at 5000 feet, from transmitted interrogations is:

AVOID-I	AVOID-II	Blockage Type
.05817	.03343	Interrogations Received
.00709	.00264	Responses Received
.00659	.00393	Interrogations Transmitted
.07185 sec/sec	.04000 sec/sec	TOTALS

In actual practice transponder blockage will be less than the above calculations indicate for the following reasons:

1) It was assumed that all interrogations which had an associated multipath signal activated both channels. In practice the second channel inhibit would block the majority of the multipath signals.

2) For the AVOID-I the maximum interrogation transmitted rate can only be achieved for an aircraft in violation of an advisory and/or command.

3) It was assumed all blockage was directly additive.

The probability of an AVOID-I responding to an interrogation is therefore 0.92815 and for an AVOID-II the probability is 0.96000. The probability of an AVOID-I responding to one or more of 3 interrogations is 0.99963 for an AVOID-II this probability is 0.999936.

For AVOID-I with a threat outside the coaltitude band (-600 to +600) the probability the threat is detected is 0.997 assuming three interrogations per set. If two interrogations are made in the first three sets the probability is 0.983 of the threat being detected.

For an AVOID-I with a coaltitude threat the probability of the threat being detected is 0.995 (three interrogations per set for eight sets and three interrogations per set for five sets of correlation data). If two interrogations are made in the first three sets the probability is 0.981 of the threat being detected.

F. False Alarm Rate

To display a threat the AVOID systems require that the threat exist on two successive sequences and the last set of the first sequence is correlated, in range, with the first set of the second sequence. This, in effect, requires consistent track for 16 sets. The probability of displaying an Alarm, P(DA), is therefore:

$$P(DA) = \sum_{R=0}^{R=Rmax} [N_T \cdot P_{11} \cdot P_{12} \cdot P_{13} \cdot P_{14} \cdot P_{15} \cdot P_{16} \cdot P_{17} \cdot P_{18}] \cdot N_r \cdot [N_T \cdot P_{21} \cdot P_{22} \cdot P_{23} \cdot P_{24} \cdot P_{25} \cdot P_{26} \cdot P_{27} \cdot P_{28}]$$

where R = Range
$Rmax$ = Maximum allowable Range
N_T = Allowable number of tracks
N_R = Range correlation constant
P_{jk} = Probability the intruder equation is satisfied in sequence j, set k.

For an AVOID system, below 9600 feet, the maximum bin skip is 64 bins, The minimum allowable bin skip, is a function of range. Reference to the AVOID-I manual, Table 2, shows that the threat criteria is a bin skip of 64 at a range of 51,550 to 52,200 feet. Therefore the maximum range of an AVOID-I system below 9600 feet is 52,200 feet and N_T equals 1 for ranges between 51,550 and 52,200 feet. For others range N_T will be increased by 1 for each 650 feet below the maximum range. For example at a range of 30,000 feet the threat criteria is a bin skip of 30 providing $64 - 30 + 1 = 35$ possible tracks ($N_T = 35$).

The intruder equation, figure 7 in the AVOID-I manual, has an average width of 3.27 bins for sets 2 through 7, that is there is an average of 1220 paths from H_i to A_i through the 6 intermediate sets and $(1220)^{1/6} = 3.27$. The probability that the intruder equation is satisfied for sets 2 through 7 is therefore 3.27 times mu where mu equals the probability a single bin is occupied.

For the first and last sets of each sequence the intruder equation is one bin wide therefore the probability the intruder equation is satisfied equals the probability a single bin is occupied.

The range correlation constant for the AVOID-I system is 13, that is there is 13 bins where the second sequence can start.

The probability of a displayed alarm is therefore:

$$P(DA) = \sum_{R=0}^{R=Rmax} N_T^2 \cdot 13 \cdot (3.27)^6 \cdot mu_{11} \cdot mu_{12} \cdot \cdot \cdot mu_{18} \cdot mu_{21} \cdot mu_{22} \cdot\cdot\cdot mu_{28}$$

where mu is the target density per bin and depends on the sequence and set.

The target density per bin is the sum of asynchronous (fruit) and synchronous (response) signals. The AVOID-I fruit level is 78, 715 pulses per second. With three interrogations per altitude band per set and 100 nanoseconds per bin the fruit density per bin (F) is

$$F = 78,715 \times 3 \times 100 \times 10^{-9} = 0.0236 \text{ Targets/bin}$$

The aircraft target density per bin (A) is a function of range and is approximated by the equation:

$$A = (2\pi HPoWo)Re^{-(R/R_1)^2}$$

where H = 0.2 (probability aircraft is in interrogated band)

Po = 0.04 (aircraft density per sq.mi.)

Wo = 50.0 (Range bin width)

R = Range

R_1 = 9.0 mi. (Range density parameter)

The target density per bin for sequence 1 set 1 (mu_{11}) equals F + A:

$$mu_{11} = F+A = 0.0236 + (2\pi HoPoWo)\,Re^{-(R/R_1)^2}$$

Since the same aircraft can not satisfy two different sets, except for set 8 of sequence 1 and set 1 of sequence 2, the Aircraft target density for set 2 is lower than set 1. The target density for set 2 of sequence 1 is:

$$mu_{12} = F + (N_2/N_1)A$$

where N_1 = expected number of aircraft in set 1

N_2 = expected number of aircraft in set 2

and the relationship between N_1 and N_2 is:

$$N_2 = \frac{A}{A+F}(N_1-1) + \frac{FN_1}{A+F} = N_1 - \frac{A}{A+F}$$

for set 3 of sequence 1 the relationship between N_1, N_2 and N_3 is:

$$N_3 = N_2 - \frac{A_2}{A_2+F}$$

Where $A_2 = (N_2/N_1)A$

Using the equations given above the displayed false alarm rate for the AVOID-I and AVOID-II systems were calculated. The results are:

$P(DA) = 6.325 \times 10^{-8}$ per altitude band per sequence for AVOID-I

$P(DA) = 7.12 \times 10^{-11}$ per altitude band per sequence for AVOID-II

In the AVOID-I, the false alarm rate per hour is approximately 16,000 hours per 1300 foot altitude band. An AVOID-I in level flight interrogates two altitude bands, 0 to +1300 feet and 0 to -1300 feet. The expected false alarm rate is therefore one false alarm per 8000 hours.

In order to generate a coaltitude false alarm altitude correlation must occur in 10 of the 16 sets. The probability of altitude correlation is approximately 0.6 per set or 0.006 for 10 sets. Therefore only 0.6 percent of the false alarms will be coaltitude alarms with the remainder of the alarms as limit climb rate advisories.

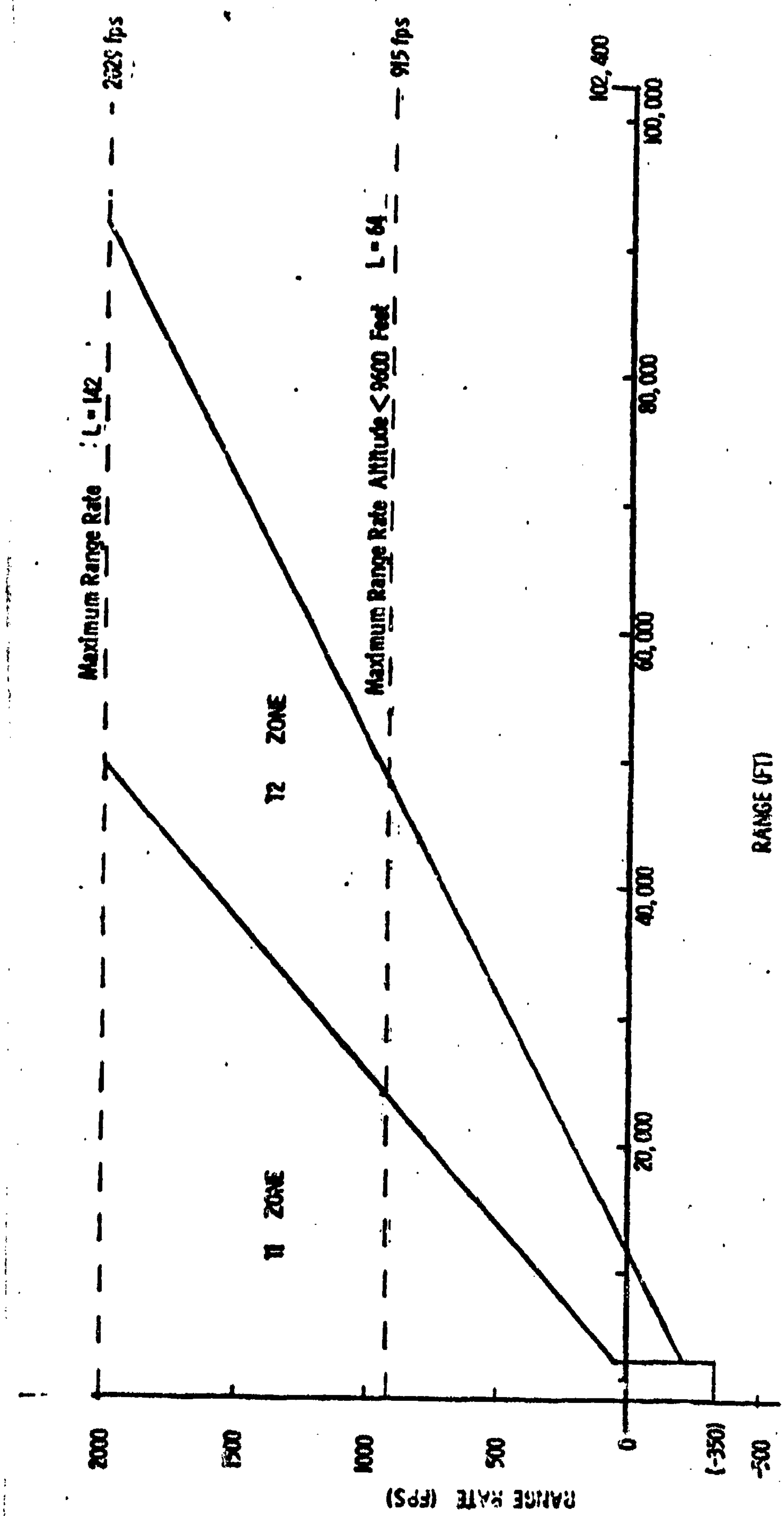
Sincerely,

HONEYWELL, INC.
Government and Aeronautical
Products Division

Roger V. Goggins
Development Engineer

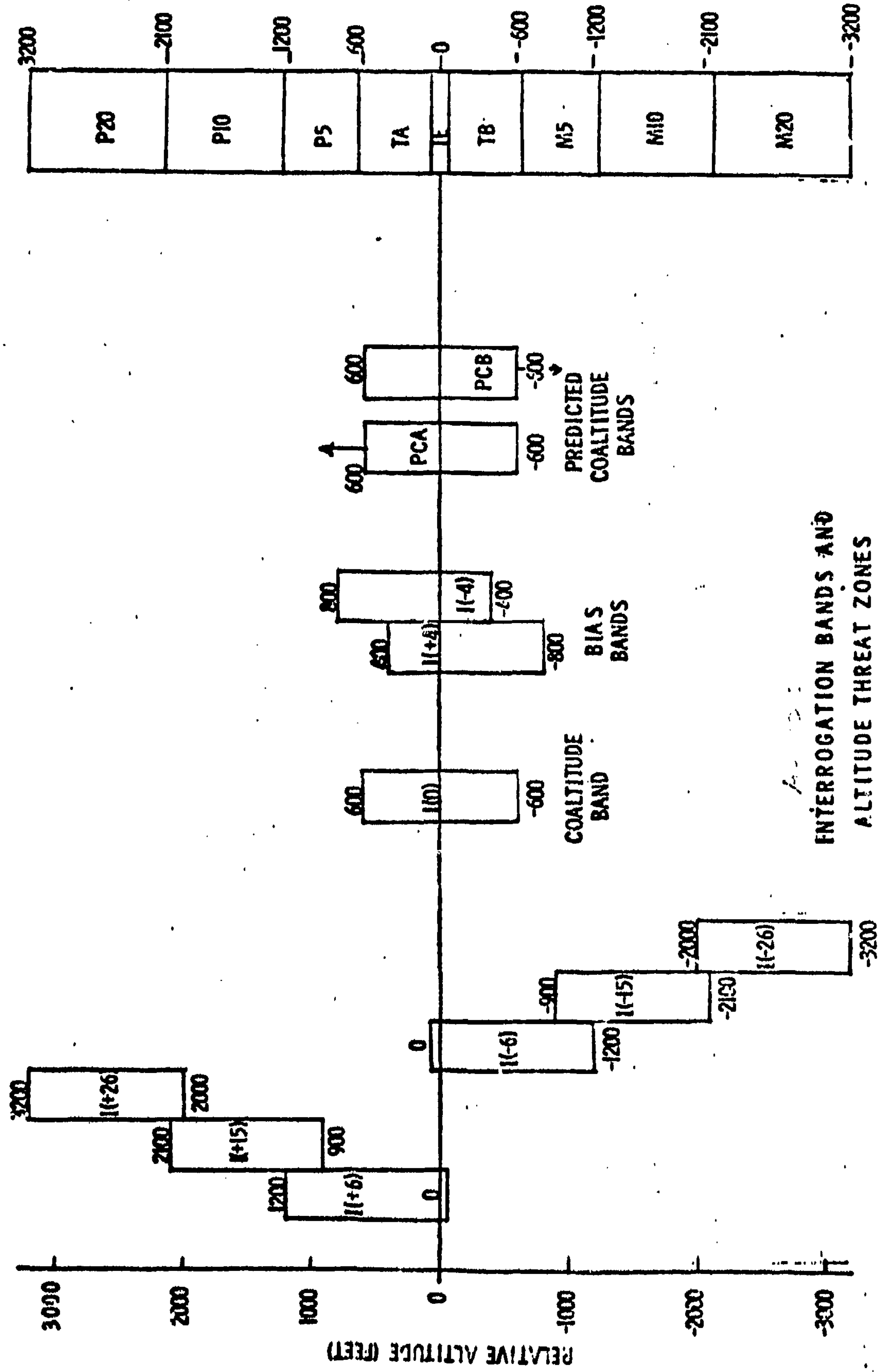
RVG/pa

ATT



AVOID-I TAU EVALUATION LIMITS

FIGURE I



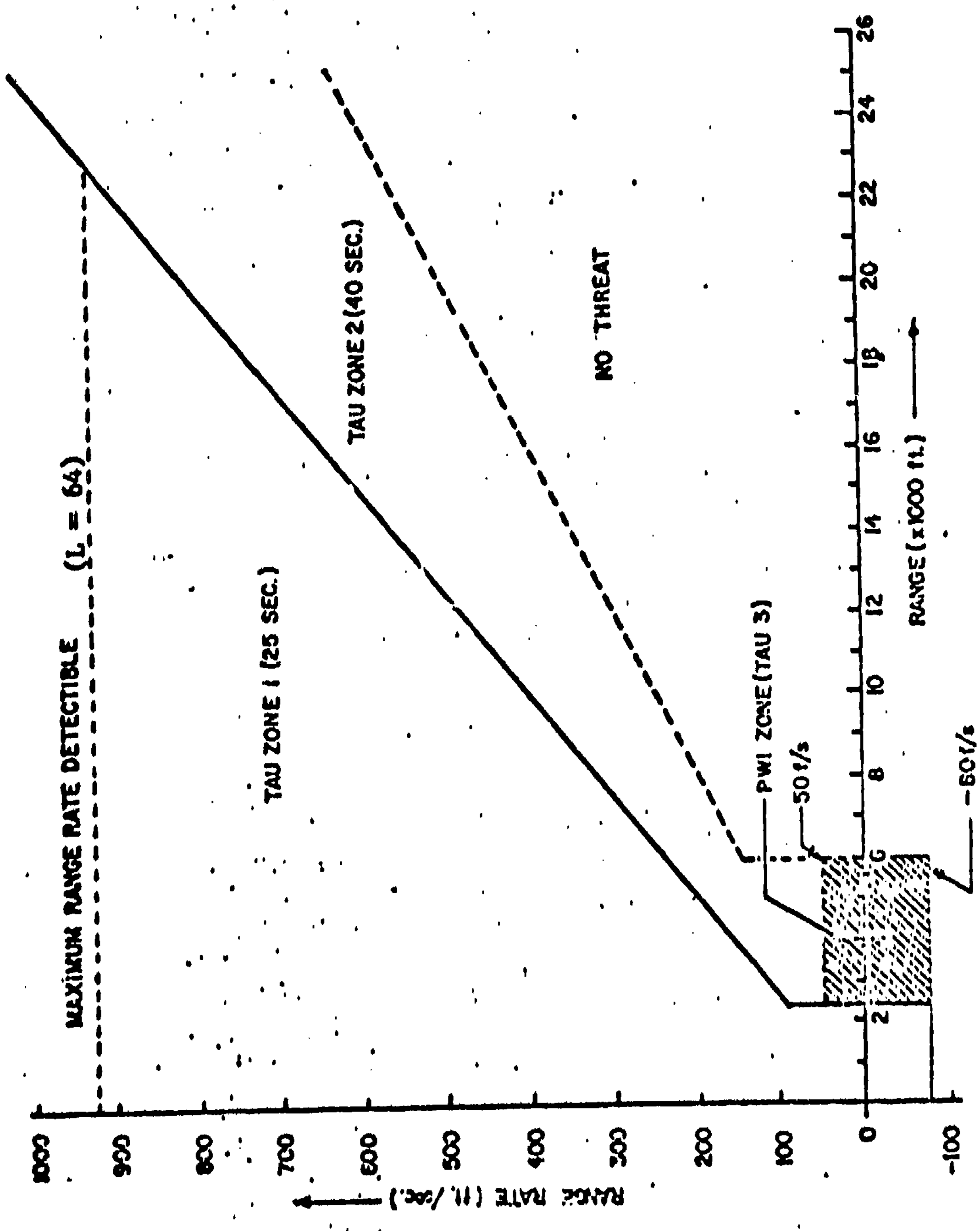
INTERROGATION BANDS AND ALTITUDE THREAT ZONES FOR ALTITUDES < 9600

FIGURE 2

ALTITUDE BAND	SET 1	SET 2	SET 3	SET 4	SET 5	SET 6	SET 7	SET 8
PCA	"0"	"0"	[T(+6) + T(+15) + T(+26)]·[$\dot{h}$>500]	H(+6) + H(+15) + H(+26)	H(+6) + H(+15) + H(+26)	H(+6) + H(+15) + H(+26)	H(+6) + H(+15) + H(+26)	H(+6) + H(+15) + H(+26)
+26	$\dot{h}$>1000	T(+26)	T(+26)	T(+26)	T(+26)	T(+26)	T(+26)	T(+26)
+15	$\dot{h}$>500	T(+15)	T(+15)	T(+15) + T(+26)	T(+15) + H(+26)	T(+15) + H(+26)	T(+15) + H(+26)	T(+15) + H(+26)
+6	"1"	T(+6)	T(+6)	T(+6) + T(-6) + T(+15)	T(+6) + H(-6) + H(+15)	T(+6) + H(-6) + H(+15)	T(+6) + H(-6) + H(+15)	T(+6) + H(-6) + H(+15)
+4	"0"	"0"	"0"	T(+6)	H(+6)	H(+6)	H(+6)	H(+6)
0	"0"	"0"	"0"	T(+6) + T(-6)	H(+6) + H(-6)	H(+6) + H(-6)	H(+6) + H(-6)	H(+6) + H(-6)
-4	"0"	"0"	"0"	T(-6)	H(-6)	H(-6)	H(-6)	H(-6)
-6	"1"	T(-6)	T(-6)	T(-6) + T(+6) + T(-15)	T(-6) + H(+6) + H(-15)	T(-6) + H(+6) + H(-15) +	T(-6) + H(+6) + H(-15)	T(-6) + H(+6) + H(-15)
-15	$\dot{h}$< -500	T(-15)	T(-15)	T(-15) + T(-26)	T(-15) + H(-26)	T(-15) + H(-26)	T(-15) + H(-26)	T(-15) + H(-26)
-26	$\dot{h}$< -1000	T(-26)	T(-26)	T(-26)	T(-26)	T(-26)	T(-26)	T(-26)
PCB	"0"	"0"	"0"	[T(-6) + T(-15) + T(-26)]·[$\dot{h}$ < -500]	H(-6) + H(-15) + H(-26)	H(-6) + H(-15) + H(-26)	H(-6) + H(-15) + H(-26)	H(-6) + H(-15) + H(-26)

AVOID - I INTERROGATION DECISION LOGIC FOR ALTITUDES ≤ 9500

FIGURE 3



AVOID-II TAU ZONES

FIGURE 4

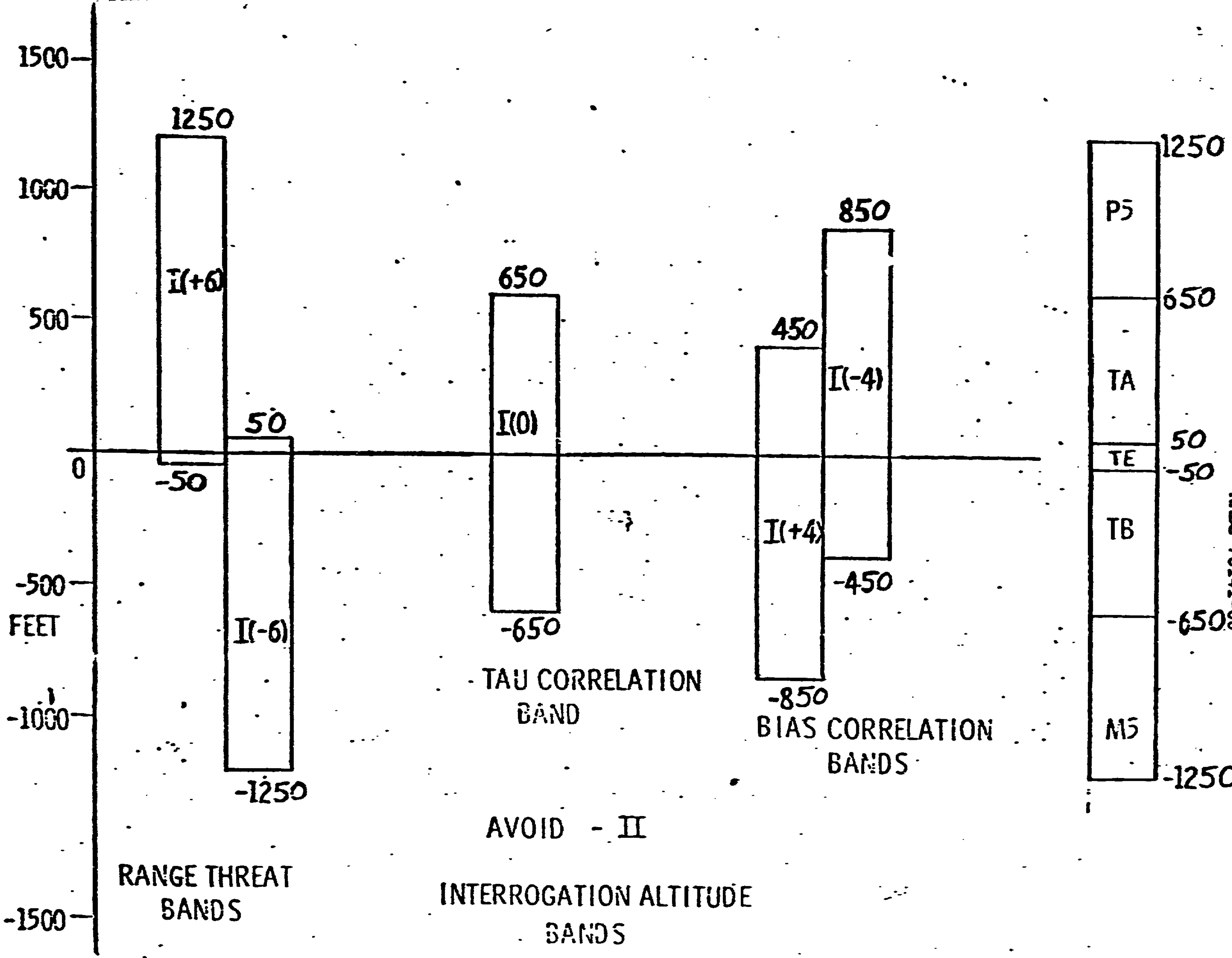

1500
1000
500
0
-500
FEET
-1000
-1500
1250
I(+6)
-50
50
I(-6)
-1250
RANGE THREAT BANDS
650
I(0)
-650
TAU CORRELATION BAND
450
I(+4)
-850
850
I(-4)
-450
BIAS CORRELATION BANDS
1250
P5
650
TA
50
TE
-50
TB
-650
M5
-1250
AVOID - II
INTERROGATION ALTITUDE BANDS

FIGURE 5

ALTITUDE BAND	SETS							
	A	B	C	D	E	F	G	H
I(+6)	"I"	T(+6)	T(+6)	T(+6) OR T(-6)	T(+6) OR H(-6)	T(+6) OR H(-6)	T(+6) OR H(-6)	T(+6) OR H(-6)
I(+4)	"0"	"0"	"0"	T(+6)	H(+6)	H(+6)	H(+6)	H(+6)
I(0)	"0"	"0"	"0"	T(+6) OR T(-6)	H(+6) OR H(-6)	H(+6) OR H(-6)	H(+6) OR H(-6)	H(+6) OR H(-6)
I(-4)	"0"	"0"	"0"	T(-6)	H(-6)	H(-6)	H(-6)	H(-6)
I(-6)	"I"	T(-6)	T(-6)	T(-6) OR T(+6)	T(-6) OR H(+6)	T(-6) OR H(+6)	T(-6) OR H(+6)	T(-6) OR H(+6)

NOTE: T(X) INDICATES A VALID TRACK THROUGH PREVIOUS SET IN BAND X
H(X) INDICATES A VALID TRACK THROUGH PREVIOUS SET IN BAND X WHICH CORRELATED IN ALTITUDE

AVOID - II

INTERROGATION DECISION
LOGIC

FIGURE 6

APPENDIX B

AVOID II COLLISION AVOIDANCE SYSTEM - OPERATING INSTRUCTIONS OF MAY 1975

YG1161A01

AVOID-II

COLLISION AVOIDANCE SYSTEM(M)

OPERATING INSTRUCTIONS

MAY 1975

Prepared Under Contract Number N62269-75-C-0149

for

NAVAL AIR DEVELOPMENT CENTER

DEPARTMENT OF THE NAVY

by

R.V. GOGGINS

HONEYWELL, INC.
Government & Aeronautical Products Division

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1.0 SYSTEM DESCRIPTION

1.1 General

The AVOID-II is an aircraft Collision Avoidance System (CAS) that generates advisories and/or commands based on the relative altitude, range, and range rate of all intruder aircraft.

The advisories provide the pilot with a visual indication of safe manuevering limits. The commands indicate the appropriate escape manuever.

Commands:

A command is displayed if the projected time to collision is less than 25 seconds and/or the intruder range is less than 2500 feet <u>and</u> the intruder relative altitude is less than 650 feet. The commands are DIVE, CLIMB, or FLY LEVEL.

Advisories:

An advisory is displayed if the projected time to collision is less than 40 seconds and/or the intruder range is less than 6000 feet <u>and</u> the intruder relative altitude is less than 1250 feet. The advisories are LIMIT CLIMB TO 500 FPM and LIMIT DIVE TO 500 FPM.

Range Data:

In addition to the commands and advisories, the range is displayed for all intruders whose projected time to collision is less than 40 seconds and/or the intruder range is less than 6000 feet <u>and</u> the intruder relative altitude is less than 650 feet. The range data is provided in 1000 foot increments from zero to 8000 feet and in 2000 foot increments from 8000 to 24,000 feet. A separate display is provided for the above and below bands.

1.2 General System Operation

The AVOID-II system operates on a cooperative basis with other like equipped aircraft. The system is, in effect, a 1.6 GHz pulse beacon ranging system. Each CAS serves both an interrogation and response function. There are three modes of operation: interrogation, response, and self test.

During the interrogation mode, pulse-coded RF energy is radiated from two antennas mounted on the aircraft surfaces. All other similarly equipped aircraft, within communication range receive the coded interrogation. The interrogation pulses specify the altitude that is being interrogated.

In the response mode, the AVOID system compares the interrogated altitude with its own altitude, a response consisting of a single pulse is transmitted if the altitude comparison indicates the interrogated altitude is within 650 feet of own altitude.

1.2 General System Operation (Cont.)

The AVOID-II is in the response mode a minimum of 99.7 per cent of the time.

In the self test mode, the AVOID system has normal operation except the transmitted interrogation is received as a response signal.

The AVOID system determines an intruders range by the two way transmission delay, range rate by comparing ranges over a 3.5 second period, and the relative altitude by comparing responses received at the altitudes interrogated.

1.3 Equipment Description

The AVOID-II CAS is composed of:

Interrogator/Transponder Unit HG1035AA01

Indicator Unit SK132316

Antennas, two per installation, omnidirectional

Ancillary Equipment:

In the AVOID-II system, the required altitude data is supplied by an Encoding Altimeter.

1.4 System Parameter Summary

Power Output	+54 dbm (minimum)
Carrier Frequency	1607.5 ± 1.5 MHz
Modulation Type	Pulse Coded
Pulse Width	100 ± 20 nanoseconds
PRF (Interrogations)	Maximum of 93 per 3.75 second sequence
Time/Sequence	3.75 ± 0.20 seconds (jittered)
Receiver Sensitivity	-68 dbm minimum
Local Oscillator Frequency	1547.5 ± 1.0 MHz
Protected Volume	
Range	0 to 25,600 feet
Altitude	± 1250 feet relative
Accuracy (full environmental)	
Range	± 300 feet
Range Rate	± 17 feet/sec
Warmup Time	2 minutes
Power Requirements	28 VDC, 3 amps 115 VAC, 0.35 amps
Weight	Transponder - 11 lbs Display - 2 lbs.
Size	Transponder 3/8 ATR Short Display 75 in.^{3}

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In the response mode, the AVOID system compares the interrogated altitude with its own altitude, a response consisting of a single pulse is transmitted if the altitude comparison indicates the interrogated altitude is within 650 feet of own altitude.

2.0 System Operation

2.1 Interrogation Message

The interrogation message format is given at the top of Figure 1. The first two pulses in an interrogation message are separated by 500 nanoseconds and the second two pulses by 600 nanoseconds. The first two pulses (pulse pair one) indicate the start of an interrogation message and can thus be distinguished from the second two pulses (pulse pair two) which complete the interrogation message.

The separation between the first and third pulse, start of pulse pair one to start of pulse pair two, indicates the interrogated altitude. This separation is equal to 32.5 microseconds plus 2.0 nanoseconds per foot of altitude referenced to -1200 feet MSL. The 32.5 microsecond fixed delay reduces the probability that a delayed multipath signal will interfere with reception of the second pulse pair.

By use of pulse pairs in the interrogation message the interrogation pulses are distinguished from the single pulse response signal.

2.2 Interrogation Response

On decoding a pulse pair one the responding aircraft generates a 2.6 microsecond wide altitude acceptance window. This window is centered 32.6 microseconds plus responding aircraft's own altitude code after the decoded pulse pair one.

On decoding a pulse pair two the decoded pulse is gated to the send response circuit by the altitude acceptance window. The responding aircraft will thus respond to all interrogated altitudes from -650 to +650 feet of it's own altitude.

The actual response is a single pulse generated 32.7 microseconds after a "Hit" (pulse pair two decoded and gated by the altitude acceptance window) occurs.

2.3 Range Data Storage

Responses to interrogations are clocked into a high speed (512 X 1) random access memory (RAM). The RAM address counter is gated on 32.7 microseconds after transmission of the fourth interrogation pulse. (See figure 1).

With no propogation delay the response will be clocked into the first memory address by the first clock pulse. Responses received from aircraft at various ranges will be clocked into the RAM as they are received. The result is a digitized range measurement of all responding aircraft.

The two way propogation delay of 2 nanoseconds per foot, and the RAM address counter clock period of 100 nanoseconds digitizes the range in 50 foot increments.

After completion of an interrogation the data in the RAM is transferred to one or more 512 bit static shift registers.

2.4 Interrogation Sequence Timing

The complete interrogation sequence is a 3.75 ± 0.20 second interval. The ±0.2 second jitter in each sequence prevents sequence synchronization with other aircraft. The sequence is shown in figure 2.

A complete sequence consists of seven intervals of 0.5 seconds each and an eighth interval of 0.05 to 0.45 seconds.

2.4.1 Clock

The basic timing for the interrogation sequence is generated from a 3.0 ± 0.5 millisecond jittered clock. Interrogations are synchronized with this clock. The jitter between interrogations prevent two aircraft from synchronizing their interrogations.

2.4.2 0.5 Second Time Interval

The 0.5 second time interval is obtained by counting 166 pulses from the 3 milli second clock. The average clock period being set to provide the 0.5 second interval.

2.4.3 Set 8 Time Interval

The set 8 time interval is determined by the interrogation period the evaluation period and a 0.2 second jitter. The minimum time required for interrogations and evaluations is 0.05 seconds. The maximum time required for interrogations and evaluations is 0.25 seconds. The minimum set 8 time is thus 0.05 seconds and the maximum time is 0.45 seconds.

2.5 Interrogated Altitude Bands

The AVOID-II receives altitude digitized in 100 foot increments from an encoding altimeter. It can interrogate it's own altitude and four additional altitudes. The four additional altitudes are 600 feet above, 200 feet above, 200 feet below, and 600 feet below it's own altitude.

An AVOID system being interrogated will respond if the interrogated altitude is between -650 and +650 feet of it's own digitized altitude or, since the altitude is digitized in 100 foot increments, the AVOID responds to 13 altitude codes. The 13 altitude codes relative to it's own altitude are ±600, ±500, ±400, ±300, ±200, ±100, and 0 feet.

An interrogated altitude band is thus the 13 altitudes from which responses are received. The +600 foot interrogation referred to as the +6 band are the relative altitudes of 0 to +1200 feet. The -600 foot interrogation referred to as the -6 band are the relative altitudes of 0 to -1200 feet. The own altitude interrogation referred to as the 0(zero) band are the relative altitudes of -600 to +600 feet. The -200 foot interrogation is referred to as the +4 band and are the relative altitude of +400 to -800 feet. The +200 foot interrogation is referred to as the -4 band and includes the relative latitudes of -400 to +800 feet.

Figure 3 shows the logic that determines which bands are interrogated in each set. The +6 and -6 bands are used to determine the range/range rate of a threat and are thus interrogated in the first set (set A) and in each succeeding set until it has been determined that no threat exists in that band. The 0, +4, and -6 bands are used for altitude correlation with the +6 band. They are interrogated in the fourth set (Set D) if a potential threat exists in the +6 band. In the remaining sets they are interrogated if their is a potential threat in the +6 band that is also in the interrogated band. The 0, -4, and +6 bands are interrogated in the fourth set if a potential threat exists in the -6 band. In the remaining sets they are interrogated if a potential threat exists in the -6 band that is also in the interrogated band.

2.6 Interrogations per Altitude Band

The number of interrogations, of an altitude band, during a set, is determined by the set number and the threat status.

In sets A, B, and C, if a threat has not been detected in an altitude band during one or both of the two previous sequences two interrogations are made in that band. If a threat was detected, then three interrogations are made. In sets D, E, F, G, and H three interrogations are made in all interrogated bands regardless of the threat status during the previous sequences.

2.7 Threat Evaluation

The Tau zones are shown in Figure 4 and the Altitude zones in Figure 5. The Tau zones are determined from the Range, Range Rate relationship as derived from the +6 and/or -6 interrogations. The altitude zones are determined by comparing the responses from a threat in the +6 and/or -6 band with responses from other bands. This process is referred to as altitude correlation.

2.7.1 Tau Zones

Potential collision threats are assigned to one of three "TAU" zones. These zones are:

R/$\dot{R}$ Relationship	Tau Zone
$R \leq 25\dot{R}$	1
$R \leq 2500$ feet	1
$R \leq 40\ \dot{R}$	2
$R \leq 6000$ feet	2
$2500 < R < 6000$ feet and $-80 < \dot{R} < 50$	3

Where R = Range to Intruder (ft)
$\dot{R}$ = Relative Range Rate (ft/sec)

Figure 4 shows these zones on a R, $\dot{R}$ map.

2.7.2 Altitude Zones

In addition to the three Tau zones there are 4 altitude zones. The altitude zones are defined below and shown in figure 5.

Threat Relative Altitude (Digitized)	Altitude Zone
+700 to +1200	Above
0 to +600	Coaltitude Above
0 to -600	Coaltitude Below
-700 to -1200	Below

2.8 Altitude Bias Logic

The altitude bias logic prevents two aircraft from receiving the same command. When an aircraft has 0 bias the aircraft responds to interrogations normally, with positive bias the response altitude is shifted 200 foot higher than actual altitude and, with negative bias the response altitude is shifted 200 feet lower.

The bias when applied is in the direction of an impending manuever. That is an aircraft which will receive a Climb command has positive bias and an aircraft that will receive a Dive command has negative bias.

Altitude bias occurs when a valid threat has a relative altitude of -400 to +400 feet, the +400 and -400 altitude bands are used to determine if bias is required. For the equal altitude encounter the direction of the bias is selected at random. Since the first aircraft to bias will no longer respond as an equal altitude threat the second aircraft will bias in the opposite direction.

In order to determine if altitude bias is required the two coaltitude zones are divided into the 5 altitude zones shown below.

Relative Altitude	Altitude Zone	Altitude Bias
500 to 600	Coaltitude Above	Not Required
100 to 400	Coaltitude Above	Negative
0	Equal Altitude	Random
-100 to -400	Coaltitude Below	Positive
-500 to -600	Coaltitude Below	Not Required

2.9 Threat Zones

The three tau zones and seven altitude zones give a total of 21 possible threat combinations. In addition, the equal altitude threat can be obtained from the +6 or the -6 band giving a total of 24 threat combinations. These are defined in figure 6 in terms of relative altitude and tau zone.

2.10 Intermediate Display Logic

The functions of the intermediate display logic are to inhibit the display of a false threat, to maintain the displayed threat, when a threat is lost for one sequence, and to incorporate the altitude bias in the displayed threat for an equal altitude encounter. The intermediate display logic equations are given in figure 7.

2.11 Indicator Display Logic

2.11.1 Command and Advisory Display Logic

The output of the intermediate display logic is applied to the Command Display Logic. The command display logic controls the two advisory and 3 command lights on the indicator. The advisories are limit climb to 500 fpm and limit dive to 500 fpm. The commands are climb, level, and dive. The command and advisory display logic is given in Figure 8.

2.11.2 Range Light Display Logic

The 32 Range lights in the AVOID-II Indicator provide the range of all coaltitude, +600 to -600 threats. The 32 lights, 16 above and 16 below, provide range data in 1000 foot increments from 0 to 8,000 feet and 2000 foot increments from 8,000 to 24,000 feet.

A Tau 1 or Tau 2 threat is displayed as a flashing range light with a Tau 3 displayed as a solid light. The displayed range data is set H data which is transmitted to the display during the set H evaluation. The Range light display logic equations are given in figure 8.

2.12 Automatic Operation Controls

In a terminal area certain functions are automatically inhibited. These inhibits are listed in Table 4.

3.0 Detail Theory of Operation (Interrogator/Transponder)

The AVOID-II Interrogator/Transponder consists of four functional modules in a 3/8 short ATR chassis.

These four modules are:

- Transmitter
- Receiver
- Power Supply
- Digital Processor

A block diagram of the system is shown in figure 9.

3.1 Transmitter

The transmitter module consists of the high voltage power supply, a power on time delay, modulator, and a cavity tuned oscillator/amplifier tube pair.

The high voltage power supply provides a regulated 1600 VDC to the plates of the oscillator/amplifier tube.

The time delay is generated by a 555 timer. It blocks the transmitter from operating until the oscillator/Amplifier tube has warmed up. The nominal time delay is 90 seconds.

The modulator converts the TTL input signal to the required drive signal for the oscillator and protects the TTL circuits from high voltage feedback by the oscillator/amplifier tube.

The cavity tuned vacuum tube oscillator/amplifier is a cathode modulated tube pair. The output is generated by grounding the cathode of the oscillator tube.

The transmitter module generates a single output pulse for each input pulse to the pulse modulator. The output is a 100 ± 20 nanosecond pulse at 1607.5 ± 1.5 MHz with a minimum power of +57 dbm.

3.2 Receiver

The receiver consists of the RF Head and the IF amplifier. A block diagram of the RF Head is shown in figure 10. It consists of a power divider, duplexer, band pass filter, limiter, balanced mixer, IF pre-amp and solid state oscillator.

The solid state oscillator is tuned to 1547.5 MHz. The IF frequency is then 60 MHz for a received signal at 1607.5 MHz.

The RF duplexer and power divider divide the transmitter output between the two antennas and route the received signals to the single channel receiver.

The IF amplifier has two IC amplifiers, a detector, and a transistor output. The first amplifier is AGC controlled and the transistor output is TTL compatible. The IF bandpass is 40 to 80 MHz. Output pulses are generated for each input pulse that has a power level of -22 to -68 dbm and are separated by 400 nanoseconds or greater.

3.3 Power Supply

The power supply generates three DC and one AC voltage from 28 volts DC input power. The output voltages are:

- 6.3 VAC
- +12 VDC
- -12 VDC
- +5 VDC

The power supply consists of a switching regulator, a DC to AC Invertor, rectifiers and output filtering.

The switching regulator converts the 28 VDC input to a regulated 18 VDC input to the invertor.

The invertor provides a 6.3 VAC output and input voltages for the $\pm$12 volt and 5 volt rectifier and filter networks.

The switching regulator is set to obtain the 5VDC output. A select resistor is then used to establish the AC output at 6.3 VRMS. The plus and minus 12 volt outputs are maintained at the correct voltage by series regulators.

3.4 Digital Processor

The digital processor performs the following functions:

- Analysis of the received interrogation and generating a response as required
- Interrogates other systems as required by the threat status
- Evaluates received responses separating threats from nonthreatening intruders and fruit
- Analyze all threat data to determine the required interrogations altitude bias and display
- Automatically inhibits selected functions in terminal areas

The Interrogation/Response circuit and the Interrogation/Evaluation Control circuit control the data flow. The Interrogation/Response circuit is primarily responsible for external data i.e., interrogations and responses with the Interrogation/Evaluation control controlling internal data flow and requesting interrogations.

3.4.1 Response Mode

A block diagram of an AVOID-II system, in the response mode, is shown in figure 11. The digital processor sections used in the response mode are:

- Crystal Clock
- Pulse Pair Decoders
- Altitude Decoder
- Altitude Bias
- Interrogation/Response Circuit

The Crystal Clock, Pulse Pair Decoders, Altitude Decoder, and Altitude Bias are all inputs to the interrogation response circuit. The output of the Interrogation/Response circuit is a pulse to the transmitter when a response is required and an interrogation inhibit signal to the Interrogation Timing

circuit when a response is being processed.

3.4.1.1 Crystal Clock

The Crystal Clock provides a 20 MHz, 10 MHz, 625 KHz, and 312.5 KHz outputs. These frequencies are obtained by dividing a 40 MHz crystal controlled oscillator by 2, 4, 64, and 128. The 20 MHz output provides the basic timing for all response functions. Both the normal and inverted outputs are available allowing received signals to be synchronized for internal processing at 25 nanosecond intervals.

3.4.1.2 Pulse Pair Decoders

The Pulse Pair Decoders are shown in figure 12. There is a total of 4 pulse pair decoders two decoders for pulse pair one and two decoders for pulse pair two.

The use of dual pulse pair decoders reduces the probability a fruit pulse will block a received pulse pair. The second decoder, for each pulse pair, is inhibited when the first decoder is available and for 100 nanoseconds after the first decoder is triggered, this prevents a single video pulse from activating both decoders.

The input to the Pulse Pair Decoders is a 110 nanosecond video pulse with a minimum separation between pulses of 190 nanoseconds. Each video pulse goes to the "D" input and through a delay circuit to the clock input of a flip-flop. If the leading edge of the clock pulse arrives when the D input is high, a decoded pulse pair signal consisting of a 50 nanosecond pulse is generated. A pulse pair one decoder requires 600 nanoseconds to complete the decoder sequence and a pulse pair two decoder 700 nanoseconds.

3.4.1.3 Altitude Decoder

The altitude as supplied to the AVOID is digitized in 100 foot increments and in a Gray code format. The Altitude Decoder uses a PROM to convert the Gray code to a binary number.

3.4.1.4 Altitude Bias

Under certain threat conditions the AVOID system is required to respond as if 200 ft higher or lower than actual altitude. This is referred to as altitude bias. The altitude bias is determined by the threat status at the completion of each set H evaluation. The input to the Interrogation/Response circuit is by two lines, one line indicating positive bias and the second negative bias. Section 3.4.4.2 gives further details on the altitude bias circuit.

3.4.1.5 Interrogation/Response Circuit

The Interrogation/Response Circuit is diagrammed in Figure 13. It is a dual channel circuit allowing two interrogations to be processed simultaneously.

Each circuit consists of a 12 bit counter preloaded with altitude and altitude bias data. A decoded pulse pair 1 selects a phase of the 20 MHz clock and activates the counter. The counter output is decoded at preselected points for inhibits, enables, and gates as required.

The altitude acceptance window occurs 31.3 microseconds plus altitude code after a decoded pulse pair 2 is received. The window lasts for 2.6 microseconds. The accepted altitudes are thus plus or minus 650 feet from own altitude as biased, or 13 altitude codes centered about own altitude as biased, Just prior to generating the altitude acceptance window, the counters are set to zero. A "hit", decoded pulse pair 2 within the altitude acceptance window, picks a phase of the 20 MHz clock and restarts the counters. The response signal is then generated 32.7 microseconds after receiving a decoded pulse pair 2.

The trailing edge of the altitude acceptance window occurs at 33.9 microseconds plus altitude code after the channel is activated. If a hit does not occur the channel is then available for the next interrogation. If a hit occurs the channel is not available until the response has been transmitted.

Altitude Acceptance Window Inhibit - To prevent a multipath pulse pair 2 from generating a response the altitude acceptance window is gated. The gate is enabled 10 microseconds prior to the start of the window and reset by the first pulse pair 2 received after the gate is enabled.

Second Channel Inhibit - To prevent multipath from activating the second response channel, the second channel is inhibited when the first channel is available and for a time equal to the altitude code plus 5 microseconds or for 16 microseconds, whichever is less after the first channel is activated. Likewise the first channel can not be activated for 5 microseconds plus altitude code or for 16 microseconds whichever is less after the second channel is activated.

Response Inhibit - When a response is transmitted both channels of the response circuit are inhibited for 3 microseconds. This prevents the transmitted response from feeding back through the IF and activating a response channel.

Interrogation Inhibit - An interrogation inhibits both response channels from the time pulse 1 of pulse pair 1 is transmitted unitl 112 microseconds after pulse 2 of pulse pair 2 is transmitted.

3.4.2 Interrogations

A block diagram of an AVOID-II, for an Interrogation, is shown in Figure 14. The digital processor portion of the circuit consists of:

- Three Millisecond Clock
- Crystal Clock
- Threat Storage
- Interrogation/Evaluation Control
- Interrogation/Response Circuit
- Altitude Decoder
- Interrogation Timing
- High Speed Data Accumulator
- Main Memory

When an interrogation is required the Interrogation/Evaluation control makes an interrogation request to the Interrogation Timing circuit. The interrogation request is synchronized to the 3 millisecond clock. When the Interrogation/Response circuit is not processing a received interrogation, the Interrogation Timing circuit interrogates and informs the Interrogation/Evaluation control that the interrogation has been made. If the Interrogation/Response

circuit is processing a received interrogation the interrogation is not made. The interrogation request is then repeated with the next 3 millisecond clock.

The Interrogation Timing circuit interrogates according to the altitude band required and activates the High Speed Data Accumulator at the proper time to receive responses.

Between each interrogation the Interrogation/Evaluation control transfers the accumulated data to the Main Memory.

The above process is repeated until the entire interrogation set has been completed.

3.4.2.1 Three Millisecond Clock

Sequence and set timing are controlled by the Three Millisecond Clock. The clock is adjusted to give 166 clock pulses in 0.5 seconds and is jittered by ±0.5 milliseconds. The jitter prevents two aircraft from synchronizing their interrogations during a set.

3.4.2.2 Crystal Clock

The 20 MHz output of the crystal clock (see section 3.4.1.1) is the time reference for the Interrogation Timing circuit.

3.4.2.3 Threat Storage

The required interrogations for set B through H are determined by the stored threats from the preceeding evaluation (see section 3.4.4.1).

3.4.2.4 Interrogation/Evaluation Control

The 3 millisecond clock is the time base for the Interrogation/Evaluation control circuit shown in figure 15. The Interrogation/Evaluation Control counts 166 clock pulses for sets A through G. To provide jitter between sequences, a 5 Hz clock is employed to jitter the set H time. The start of set 1 requires completion of set H evaluations and a positive edge from the 5 Hz clock.

A complete sequence of 8 sets is shown in figure 2. Each set consists of 8 time intervals the first 5 time intervals are for interrogating the 5 altitude bands the next 2 intervals are for evaluating the Above and Below data. The last interval marks time until the 0.5 second set time has elapsed.

The altitude bands are interrogated in the following order:

1) +400
2) -400
3) 0
4) +600
5) -600

For each interrogation time interval a minimum of 3 clock periods are required. This maintains the correct timing from set to set regardless of the number of bands interrogated.

When an interrogation request is made and the interrogation is blocked, by the Interrogation Response circuit, the time interval is extended such that all required interrogations are made.

The minimum time to complete an interrogation set is thus 45 milliseconds. The time interval consists of 5 interrogated bands times 3 interrogations per band times 3 milliseconds per interrogation.

The logic that determines the bands to be interrogated is shown in figure 3. In simple terms, it states that the interrogated bands are those in which all previous sets indicate a potential threat exists.

In set A the only bands interrogated are the +6 and -6 and these bands are always interrogated.

In set B the +6 band is interrogated if a response was received in the +6 band in set A. The -6 band is interrogated if a response was received in the -6 band in Set A.

In set C the +6 band is interrogated if the responses received in the +6 band during sets A and B indicate a potential threat. The -6 band is interrogated if the responses in the -6 band during sets A and B indicate a potential threat.

In set D a potential threat in the +6 band during the three previous sets requires interrogations of the +6, +4, 0, and -6 bands.

A potential threat in the -6 band requires interrogations in the +6, 0, -4, and -6 bands.

In set E and all remaining sets the +6 band is interrogated if the data from all previous sets indicate a potential threat in the +6 band or a potential threat in the -6 band which has altitude correlation (see section 3.4.2.5.3) with the +6 band. The +4 band is interrogated for a potential threat in the +6 band which has correlated in altitude with the +4 band. The 0 (zero) band is interrogated if a potential threat in the +6 or -6 bands has correlated in altitude with the 0 band. The -4 band is interrogated if a potential threat in the -6 band has correlated in altitude with the -4 band. The -6 band is interrogated if a potential threat exists in the -6 band or a potential threat in the +6 band has correlated in altitude with the -6 band.

.4.2.5 Interrogation/Response Circuit

To make an interrogation requires a leading edge from the 3 millisecond clock. The Interrogation/Response circuit blocks this leading edge to the Interrogation Timing circuit, whenever a response is being processed. Once an interrogation has started the response channels are inhibited as specified in section 3.4.1.5.

.4.2.6 Altitude Decoder

See section 3.4.1.3.

3.4.2.7 Interrogation Timing

The interrogation timing is sychronized to the 20 MHz clock and is implemented by use of counters (Figure 16). When an interrogation is to be made the first clock pulse disables the response circuit. The second clock pulse loads the counters with the required altitude and altitude band data. The 3rd clock pulse then starts the counters and generates the send first pulse pair signal.

To determine spacing between the two pulse pairs the decoded altitude is added, by 12 bit adders to the altitude band data from the Interrogation/ Evaluation Control. Then, at a predetermined count the send pulse pair two signal is generated followed 33.3 microseconds later by a signal that starts the high speed data accumulator. This signal is also sent to the Interrogation/Evaluation Control circuit to indicate an interrogation has been made.

The pulse pair encoder is a 16 bit shift register clocked by the 20 MHz clock. The send pulse pair 1 signal starts the shift register, and enables the 10th output. The send pulse pair 1 and the delayed signal, from the 10th register, trigger the transmitter. The send pulse pair 2 signal starts the shift register and enables the 12th output. The send pulse pair 2 and the delayed signal, from the 12th register, trigger the transmitter.

3.4.2.8 High Speed Data Accumulator

The high speed data accumulator receives responses at a 10 MHz rate and then transfers the results to the main memory at a 312 KHz rate. The accumulator consists of a 512 X 1 random access memory (RAM) and an address counter. The address counter is clocked at a 10 MHz rate giving 100 nanoseconds or 50 feet per RAM address. A received response writes a "1" into the present address of the RAM. As the received data is transfered to the Main Memory a "0" is written into each RAM address. The sequence of events is:

- The Interrogation Timing circuit clears address counter to zero.
- STAC (Start Accumulator) places a "1" on RAM data input line and starts address counter clocking at a 10 MHz rate.
- A received response writes a "1" at present address.

After 512 RAM addresses have been sequenced through, the 10 MHz clock is removed and the Interrogation/Evaluation control is signaled that accumulation is completed. Data is then transferred to the Main Memory location(s) selected by the Interrogation/Evaluation control on command from the Interrogation/Evaluation control.

3.4.2.9 Main Memory

The Main Memory consists of 28 shift registers of 512 bits each. The shift registers are divided into two groups of 14, one set for+6 range data and associated altitude correlation data, the second for-6 range data and associated altitude correlation data.

For the +6 band the registers are:

Range Data Registers	Altitude Correlation Registers		
H(+6)	H(+4)	H(0)	H(-6)
G(+6)	G(+4)	G(0)	G(-6)
F(+6)			
E(+6)			
D(+6)			
C(+6)			
B(+6)			
A(+6)			

For the -6 band the registers are:

Range Data Registers	Altitude Correlation Registers		
H(-6)	H(-4)	H(0)	H(+6)
G(-6)	G(-4)	G(0)	G(+6)
F(-6)			
E(-6)			
D(-6)			
C(-6)			
B(-6)			
A(-6)			

Data from the high speed data accumulator can only enter the H registers. The data may enter 2 registers, that is the 0 band data can enter the H register for correlation with the + band and the H register for correlation with the - band. During an evaluation all H register data is filtered, that is the H data, which provides a threat as determined by all previous sets of that sequence is retained, with the remaining data deleted. After completion of both evaluations (+6 and -6) the H register data is translated to the associated G register with G data to F, F data to E, etc. During a Translation the H registers are cleared.

When an H register is receiving data from the high speed data accumulator it is OR'ed with the present data. The end result is the logical sum of all responses in an altitude band during the set.

The range data storage registers for one band are shown in figure 17 and the altitude correlation registers in figure 18. These figures also indicate how the registers are interconnected.

3.4.3 Evaluation

A block diagram of an AVOID-II for an evaluation is shown in Figure 19. The digital processor sections active during an Evaluation are:

- Three Millisecond Clock
- Interrogation/Evaluation Control
- Crystal Clock
- Shift/Tau Clock
- Main Memory
- Tau Filter
- Threat Storage

After all interrogations have been completed the Interrogation/Evaluation control activates the evaluation sequence. The Above Band is evaluated first followed by the Below Band.

An evaluation requires 514 shift clocks. For each hit in the H data register, the shift clock is interrupted and 514 Tau clocks are generated.

At completion of 514 shift clocks all data has been returned to its original position in the main memory except the H register data. The only data points returned to the H register are those associated with a potential threat.

3.4.3.1 Three Millisecond Clock

After all interrogations have been completed the next 3 millisecond clock pulse initiates the evaluation of the Above (+6) band. The Below (-6) band evaluation is initiated by the Three Milisecond clock when the Above band evaluation is completed.

3.4.3.2 Interrogation/Evaluation Control

During an evaluation the Interrogation/Evaluation Control routes the proper range and altitude correlation registers to the Tau Filter and provides the set number to the Tau Filter. It then provides a signal to the Shift/Tau Clock to commence the evaluation sequence.

3.4.3.3 Crystal Clock

The crystal clock 625 KHz and 312.5 KHz outputs are provided to the Shift/Tau clock.

3.4.3.4 Shift/Tau Clock

The Shift/Tau Clock uses the 625 KHz and 312.5 KHz Crystal Clock outputs to provide a basic 312.5 KHz four phase clock.

Phase one of the 312.5 KHz four phase clock is used for the shift clock. The tau clock uses phase three and generates a 3 mode seven phase clock.

To complete an evaluation requires 514 shift clocks. This clock shifts all registers used in the evaluation. When a data bit in the H range register appears at the input to the Tau Filter the shift clock is interrupted and the tau clock started. On the 514th shift clock the Interrogation/Evaluation control is signaled that the evaluation is complete.

The tau clock has three modes an evaluation, alignment and recirculate mode. The evaluate and alignment modes are seven phase clocks with the recirculate mode a single phase clock.

The seven phases of the Tau clock evaluate mode and the registers shifted for each phase are shown in figure 20. In this mode A data is shifted on every phase, B data on 6 of the 7 phases, C data on 5 of the 7 phases, etc. During the evaluate mode each of the 7 phases are divided onto 4 periods with the first period used to shift data and the fourth period to evaluate the data. The remaining two periods allow time for the data to stabilize in the Tau Filter. The evaluate mode requires 11 clocks of 7 phases each, the alignment mode then clocks the G data 66 times, F data 55 times, E data 44 times, etc., until the evaluation and alignment mode have clocked all registers, A through G, a total

of 77 times. The recirculate mode then clocks all registers, A through G, 437 times returning all data to its starting position.

At completion of the 3 tau clock modes the shift mode is rentered.

3.4.3.5 Main Memory

During an evaluation the A through G Data in the Main Memory is recirculated. Recirculation is through an additional 2 stage Shift register, therefore the data has been returned to its original position after 514 shift clock pulses.

During an evaluation, the H data is only recirculated if the Tau Filter indicates a potential threat. At completion of 514 shift clock pulses the H register contains only the data points associated with a potential threat.

3.4.3.6 Tau Filter

The Tau Filter implements the Intruder and Correlation equations of figure 21, the Threat equations of figure 22, the Range Correlation equations of figure 23, generates the threat constants in Tables 1,2, and 3 and outputs the resulting threats to the threat logic.

3.4.3.6.1 Data Input

In order to evaluate an outbound target the data input to the Tau Filter is skewed. This is done by the shift registers shown between the Main Memory and the Tau Filter input in figure 24. The data is skewed 1 bin (50 foot) per set allowing evaluation of intruders outbound 6 bins or 300 feet in 3.5 seconds.

3.4.3.6.2 Intruder Equation

The Intruder equation of figure 21 separates the track of a single aircraft from other aircraft and fruit pulses. It is valid for the first 72 pulses of the tau clock evaluation mode. Due to the skewed data input lines the first, A_1, data evaluated would be an Intruder moving outbound at a rate of 6 bins in 3.5 seconds. The last clock pulse (72nd) would be an intruder inbound by 64 bins in 3.5 seconds. The 64 bins represent 64 X 50 = 3,200 feet in 3.5 secs or 914.3 ft/sec.

The Intruder equation can track an aircraft deaccelerating at 1/2 g or accelerating at 1 g. As shown by figure 21 the Intruder equation is basically two equations OR'ed together. The first equation covers linear and deaccelerating aircraft and the second linear and accelerating aircraft. For phases 1, 6, and 7 of the tau clock the G_{i+2} and B_{i+2} data is not required and is thus inhibited.

The data, for the Intruder equation, that has not been determined, is assumed to be true. This is done by "forcing" the appropriate data input lines to the Tau filter.

3.4.3.6.3 Altitude Correlations

Altitude correlation occurs in parallel with the Intruder equation. There are three altitude bands to be correlated. When evaluating the +6 band these are the -6 band, the 0 band, and the +4 band.

If the -6 band correlates in the above band evaluation the intruder is 0 (zero) feet. If the +4 band correlates in the above band evaluation the intruder is from 0 to 400 feet. If the 0 band correlates in the above evaluation the intruder is from 0 to 600 feet and if correlation is NOT obtained with the zero band the intruder is from +600 feet to +1200 feet. Equivalent correlations are made in the Below Band evaluation. All intruders are thus placed in one of seven altitude zones.

For correlation both the H and G data bits in the correlation band must be within one bin of the associated data bit in the intruder equation. In set D the G correlation is forced true so only the H data is required for correlation. In the remaining sets the G correlation data is filtered H data from the previous set. If the G data correlates it indicates all previous data has correlated.

3.4.3.6.4 Tau Zone Determination

An Intruder is not a threat or potential threat unless it meets the range/range rate criteria listed in Table 1, 2, or 3. For Tau 1, 2, and 3 respectively. The threat criteria is determined from the R, $\dot{R}$ equations of section 2.7.1 modified such that the threat, as displayed, will occur according to the equations In the three Tables the first column gives the Intruder range, the second column shows the threat criteria (number of bins crossed in a 3.5 second evaluation sequence), and the third, fourth, and fifth columns show the nominal, minimum and maximu range rate that can meet the given criteria at that range.

The circuit shown in figure 25 determines an Intruders Tau Zone. It operates as follows:

The shift clock increments a counter which addresses a PROM. The PROM has an output at each position the threat constant is to be incremented. The PROM then clocks a second counter whose output is the threat constant.

Each tau clock increments a counter in the same manner as the shift clock. Since each Tau clock represents a bin skip the counter output represents range rate.

The threat constant and bin skip counters are compared. If the bin skip counter is greater than the threat constant counter the Intruder satisfies the threat criteria.

To determine the three tau zones requires three threat constants J, K, and L. The J constant determines a Tau 1 threat, the K a Tau 2, and the L at Tau 3. As implemented, a Tau 1 threat has J, K and L valid and, for a Tau 3, only L is valid.

3.4.3.6.5 **Threat Equations**

If the Intruder equation is valid and the range, range rate relationship is within the limits specified by the J, K, or L constants the data indicates a valid threat (set H) or a potential threat (sets A through G). The altitude band of the threat is then determined by the threat equations of figure 22.

In the Threat equations (figure 22) 'T' indicates a tau threat, the number 1,2, or 3 indicates the tau zone, and an H indicates altitude correlation with the indicated band. The equation:

$$TA = [T1(+6) + T2(+6) + T3(+6)] \cdot [H(+4)]$$

is read as TA equals a Tau 1, Tau 2 or Tau 3 threat in the +6 band which correlates in altitude with the +4 band.

3.4.3.6.6 **Range Correlation**

In order for a threat to be displayed the threat must occur in two successive sequences and have range correlation. The Tau Filter performs the range correlation function. The Range Correlation equations are shown in figure 23.

In a set H evaluation the range (H data) of all threats is stored in 6 shift registers. The 6 shift registers represent P5, M5, Tau Above and Equal, Tau Below and Equal, Tau 2 Above and Equal, and Tau 2 Below and Equal threats.

In set H of the following sequence, the stored threat ranges are compared with the A data of the present threat. If the comparison indicates the A data threat range is 1 bin outbound to 9 bins inbound of the previous sequence H data the appropriate enable signal is generated. The enable signal once set is only reset when the intermediate display logic has determined that the threat was missed on two consecutive sequences.

3.4.3.6.7 **Threat Storage**

Each threat as it is decoded by the Tau Filter is latched into flip flops in the Threat Storage. The stored threats determine the altitude bands to be interrogated in the next step.

3.4.4 **Threat and Display Logic**

3.4.4.1 **Threat Storage**

The Tau Filter output to the threat storage flip flops are:

P5	M5
TA	TB
T3A	T3B
T3EA	T3EB
T2A	T2B
T2EA	T2EB
T1A	T1B
T1EA	T1EB

The intermediate display logic combines the above threats into the following 14 threats:

TA	TB	T1E
T1A	T1B	T2E
T2A	T2B	T3E
T3A	T3B	T3E
P5	M5	

Figure 26 defines the threats listed above in terms of tau zone and relative altitude.

The 14 threats and the bias for 2 sequences are stored in shift registers.

3.4.4.2 Altitude Bias

The logic for determining altitude bias is given in Figure 27. This figure shows the new bias (0+), given previous bias (0) and the threat results, tau above (TA), tau below (TB), tau equal altitude above (TEAA), and Tau equal altitude below (TEAB), of the latest evaluation sequence. Each of the nine truth tables have 4 columns and 4 rows. The 4 columns are weighed with a 00, 01, 11, and 10 from left to right. The two numbers define the state of TA and TB, for example 01 indicates a TB and not a TA. The four rows are likewise weighted with a 00,01, 11 and 10 from top to bottom. These two numbers define the state of TEAA and TEAB respectively, for example, 01 indicates TEAB and not TEAA.

There are six results, 1, 0, D, $\overline{D}$, 1/2, and $\overline{1/2}$ listed in the contents of each truth table. These results are defined as follows: A "1" indicates that the conditions for the indicated bias is satisfied, with a "0" indicating the conditions for the indicated bias not satisfied. A"D" or "$\overline{D}$" indicates the results from the previous sequence determines the bias (The notes of figure 27 define D). A"1/2" or "$\overline{1/2}$" indicates the bias is determined by a random selection, the 1/2 indicating a 0.5 probability.

3.4.4.3 Display Logic

The Display Logic uses the threats as determined by the previous two sequences, the altitude bias, and the enable functions and determines what threats are displayed. The equations are given in figure 7.

The enable functions provide protection against false tracks due to fruit and non-threatening targets. It is used with all but the Tau 3 equations. Since the Tau 3 zone has a limited range and range rate this protection is not required.

The altitude bias determines if equal altitude threats are displayed as above or below threats.

In the equations given in figure 7, the terms indicated by a 0 indicated the latest sequence completed and the -3 terms indicate the previous sequence.

3.4.4.4 Indicator Display Logic

Shown in figure 8 is the command display logic and the range light display logic.

The command display logic provide the necessary signals to light the indicator command and advisory lights.

The range light display logic shows the requirements for displaying range data. The "UPDATE" signal is generated if an evaluation indicates a threat in that band. If no threat is determined, the range lights are not updated. The display is thus held for an additional sequence.

3.4.5 Automatic Operation

Certain functions and display outputs are automatically inhibited in terminal areas. These inhibits are listed in Table 4 and described below:

On the ground the AVOID-II does not interrogate or respond, and therefore, does not indicate a threat to other aircraft.

For twelve seconds after take-off the AVOID-II responds, but does not interrogate. Other aircraft during this period can thus detect an aircraft on take-off as a possible threat, however no commands are given during or shortly after take-off to a departing aircraft.

In the first 42 seconds after take-off the Dive command is inhibited.

The Dive command is also inhibited when the landing gear is down and locked.

4.0 DETAIL THEORY OF OPERATION (DISPLAY)

The AVOID-II Display provides the pilot with advisories, commands and range data as instructed by the Interrogator/Transponder.

The advisories are Limit Climb to 500 fpm and Limit Dive to 500 fpm. The commands are Climb, Level, and Dive. The range data is in the form of 32 Light Emitting Diodes (LED'S) with 16 of the LED's specifying the range of threats in the Above band and the remaining 16 LED's specifying the range of threats in the Below band.

4.1 Advisories and Commands

Each advisory and command on the AVOID-II display consists of two 28 volt lights. One side of each light is connected to +28 VDC power the other side is a connector pin. To provide an advisory or command the AVOID-II Interrogator/Transponder grounds the appropriate pin.

4.2 Range Lights

Range data is supplied by 16 LED's for the Above band and 16 LED's for the Below band. The data is in 1000 foot increments from 0 (zero) to 8000 feet and 2000 foot increments from 8000 to 24,000 feet.

A range light that is flashing indicates a Tau 1 or Tau 2 threat with a solid range light indicating a Tau 3 threat.

4.2.1 Above Band

The AVOID-II Interrogator/Transponder provides seven signals to control the Above Band range light display. These signals are:

- Display Strobe
- Clock Above
- Strobe Tau 1 or 2 Above
- Strobe Tau 3 Above
- Update Display
- Tau Above
- Tau 3 Above

The Display Strobe signal is present during set H evaluations and enables the Strobe Tau and Clock signals. This signal prevents the display from receiving all but set H data.

The Clock Above signal increments two 16 bit shift registers. One of these shift registers is used for Tau 1 or 2 Above data and the second for Tau 3 Above data. The Clock Above pulses are properly timed to obtain the 1000 and 2000 foot range increments.

In set H the Interrogator/Transponder provides a Strobe Tau Signal for each coaltitude (0 to 600 feet) threat. A Strobe Tau 1 or 2 Above writes a "1" into the Tau 1 or 2 shift register and enables the Tau 1 or 2 Transfer. A Strobe Tau 3 signal writes a "1" into the Tau 3 shift register and enables the Tau 3 Transfer.

The Update signal occurs at the start of set A. It transfers the new data to the display registers for those shift registers where the transfer has been enabled.

The Display registers have parallel outputs. The output from the Tau 3 Above Display register is AND'ED with the Tau 3 Above signal from the Interrogator/Transponder. The Tau 1 or 2 Above display register output is AND'ED with the Tau 1 or 2 Above signal and a 2Hz signal. The 2Hz signal provides a flashing display for Tau 1 and Tau 2 range data. The Tau 3 Above and Tau 1 or 2 Above signals from the Interrogator/Transponder insure the displayed range data is in accordance with the AVOID-II threat logic.

4.2.2 Below Band

The Below Band range display circuits are identical with the Above Band. The Strobe Tau 1 or 2 Below, Strobe Tau 3 Below, Clock Below, Tau Below, and Tau 3 Below perform the same functions as the equivalent Above signals. The Display Strobe and Update Display signals are used for both Above and Below Bands.

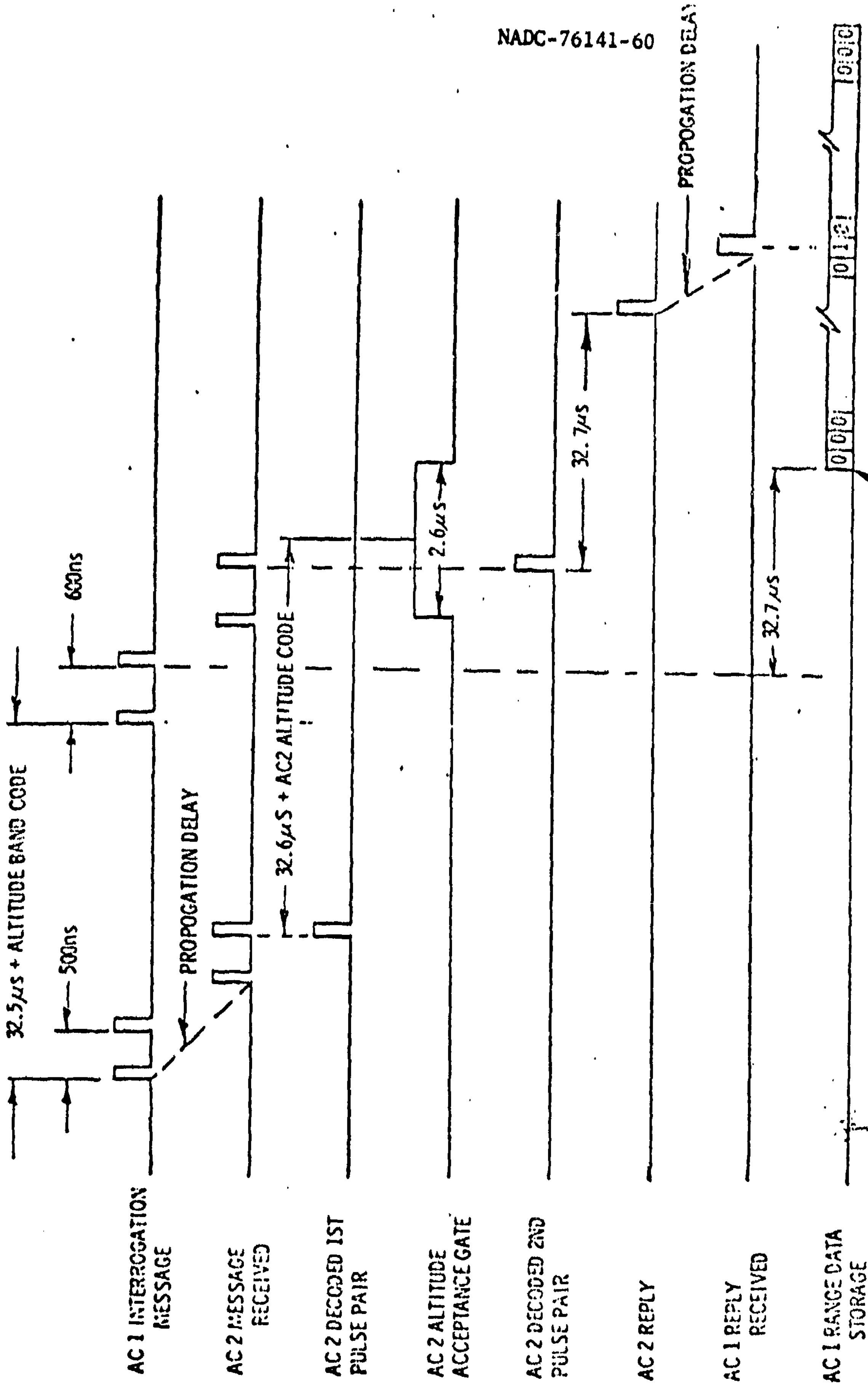
4.3 Day/Night Switch

The Day/Night switch controls the intensity of all lights on the Display. For all Advisory, Command and Background lighting a 10 volt zener diode is inserted in series with the 28 volt line for Night Operation. For the range lights the intensity of the lights are changed by pulse width modulating the drive voltage to the LED's.

A power on reset is used to provide Day Mode operation when power is first applied.

4.4 Lamp Test Switch

The Lamp Test Switch provides a 10 second Lamp Test period. When Lamp Test is activated, the Interrogator/Transponder provides the required signals to light the Advisory and Command lights. The Indicator provides the necessary signals to test all range lights. During the test mode the range lights flash (Tau 1 or Tau 2) and are lighted in sequence starting from far range. At completion of the test all 32 range lights are flashing.

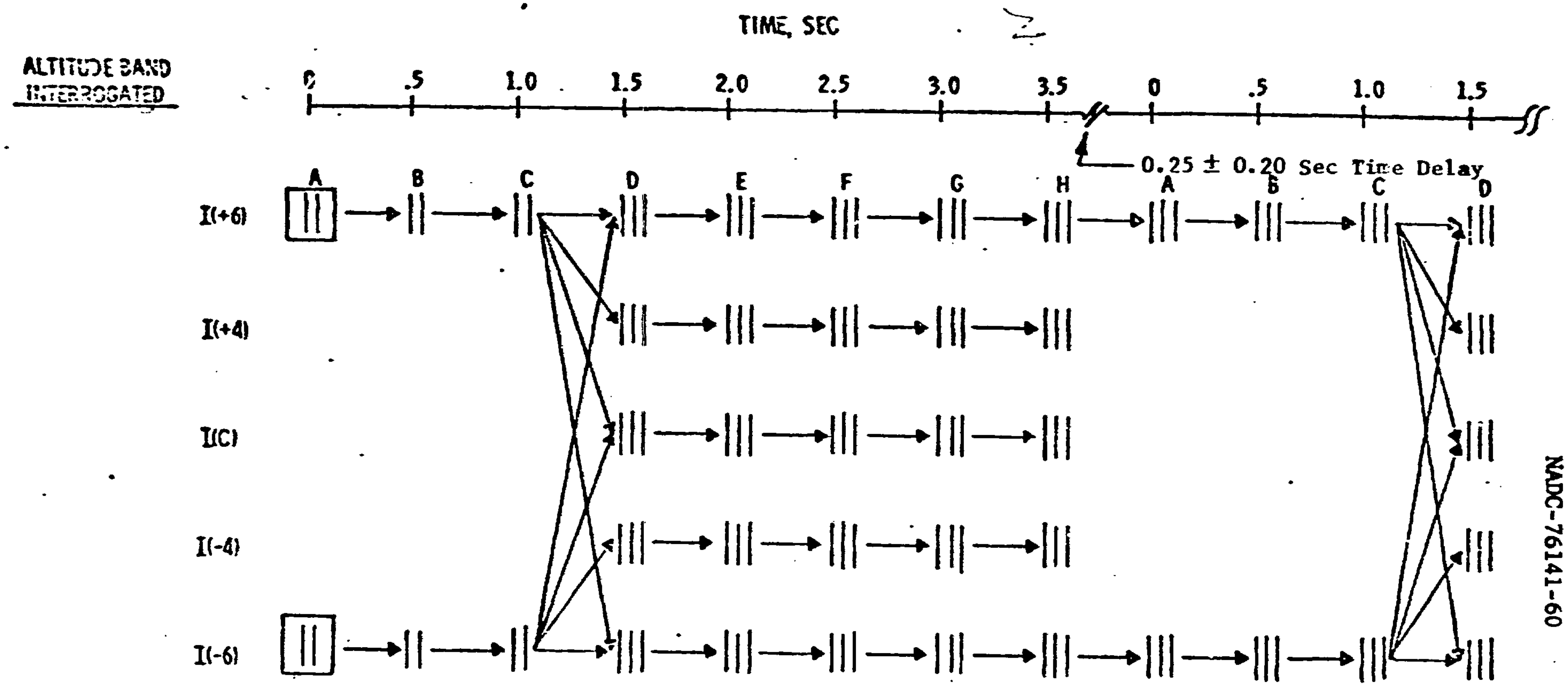


NOTE: ALTITUDE BAND CODE - 2.0 ns/ft. TO BAND CENTER REFERRED TO 1200 FEET BELOW SEA LEVEL

AVOID - II

INTERROGATION AND RESPONSE TIMING DIAGRAM

FIGURE 1



NOTE: 1. [box] DENOTES MINIMUM REQUIRED INTERROGATIONS
2. → DENOTES REQUIRED INTERROGATION ONLY IF THREAT EXISTS THROUGH PREVIOUS SETS
3. IN SETS A, B, AND C THREE INTERROGATIONS ARE REQUIRED UNLESS PREVIOUS 2 SEQUENCES INDICATED NO THREAT IN BAND

AVOID-II
INTERROGATION SEQUENCE

FIGURE 2

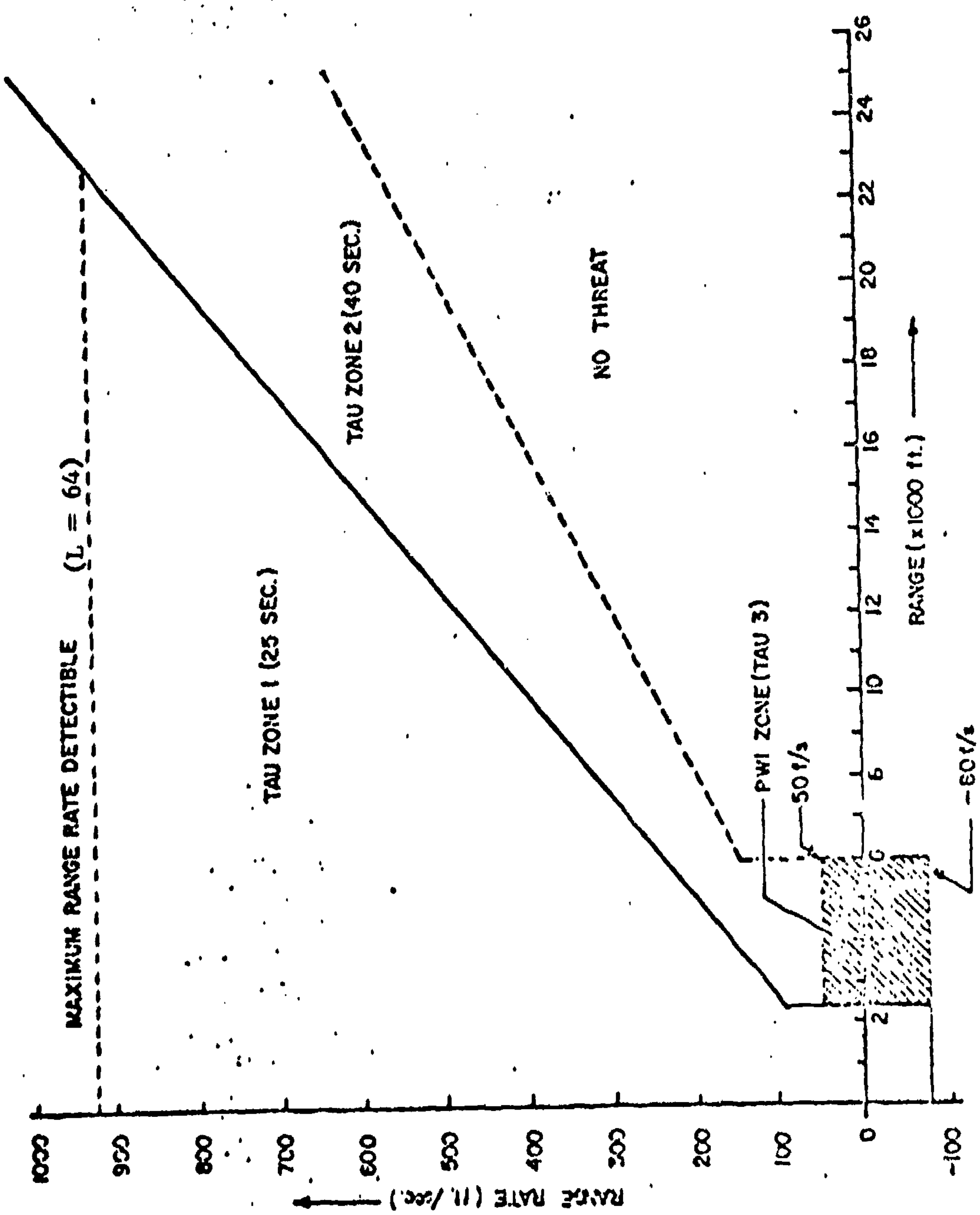
ALTITUDE BAND	SETS							
	A	B	C	D	E	F	G	H
I(+6)	"I"	τ(+6)	τ(+6)	τ(+6) OR τ(-6)	τ(+6) OR H(-6)	τ(+6) OR H(-6)	τ(+6) OR H(-6)	τ(+6) OR H(-6)
I(+4)	"O"	"O"	"O"	τ(+6)	H(+6)	H(+6)	H(+6)	H(+6)
I(O)	"O"	"O"	"O"	τ(+6) OR τ(-6)	H(+6) OR H(-6)	H(+6) OR H(-6)	H(+6) OR H(-6)	H(+6) OR H(-6)
I(-4)	"O"	"O"	"O"	τ(-6)	H(-6)	H(-6)	H(-6)	H(-6)
I(-6)	"I"	τ(-6)	τ(-6)	τ(-6) OR τ(+6)	τ(-6) OR H(+6)	τ(-6) OR H(+6)	τ(-6) OR H(+6)	τ(-6) OR H(+6)

NOTE: τ(X) INDICATES A VALID TRACK THROUGH PREVIOUS SET IN BAND X
H(X) INDICATES A VALID TRACK THROUGH PREVIOUS SET IN BAND X WHICH CORRELATED IN ALTITUDE

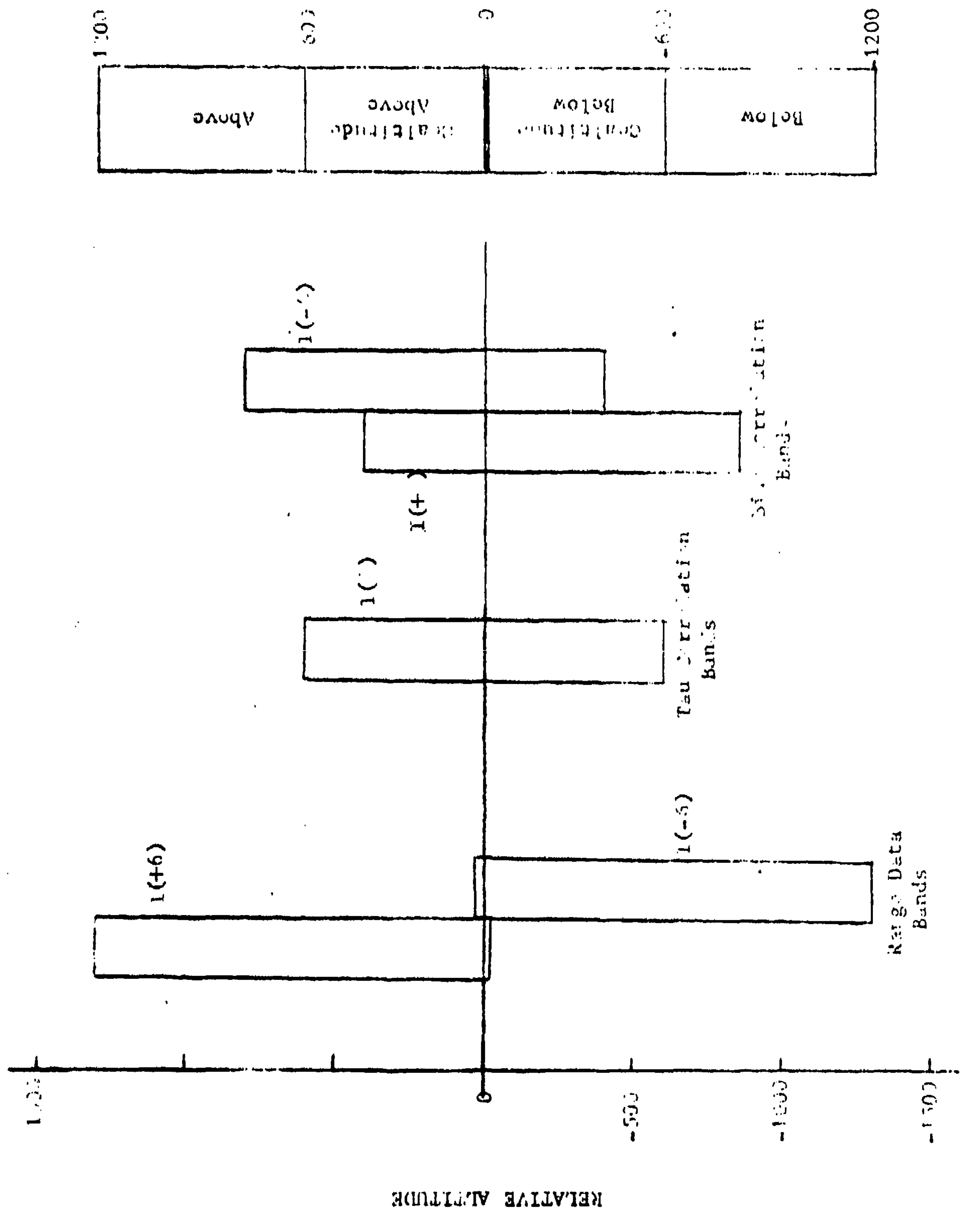
AVOID - II

INTERROGATION DECISION LOGIC

FIGURE 3



AVOID-II
TAU ZONES
FIGURE 4



AVOID-II
ALTITUDE BANDS
FIGURE [illegible]

ALTITUDE ZONE	TAU ZONE	THREAT
700 to 1200	3	P5
	2	P5
	1	P5
500 to 600	3	T3A
	2	T2A
	1	T1A
100 to 400	3	T3A (Neg.Bias)
	2	T2A(Neg.Bias)
	1	T1A(Neg.Bias)
0	3	T3EA & T3EB (Random Bias)
	2	T2EA & T2EB (Random Bias)
	1	T1EA & T1EB (Random Bias)
-100 to -400	3	T3B(Pos.Bias)
	2	T2B(Pos.Bias)
	1	T1B(Pos.Bias)
-500 to -600	3	T3B
	2	T2B
	1	T1B
-700 to -1200	3	M5
	2	M5
	1	M5

AVOID-II

THREAT ZONES

FIGURE 6

$$
{}_{\tau}1A(0)^{1} = \Big[{}_{\tau}1A(0)\circ\overline{(+\,\mathrm{BIAS}(0)\circ{}_{\tau}A(0))} + {}_{\tau}1E(0)(-\mathrm{BIAS}(0))
$$
$$
+ {}_{\tau}1A(-3)\circ\overline{(+\,\mathrm{BIAS}(-3)\circ{}_{\tau}A(-3))} + {}_{\tau}1E(-3)(-\mathrm{BIAS}(3))\Big]\Big[\overleftarrow{{}_{\tau}1A}\ \mathrm{ENABLE}\Big]
$$

$$
{}_{\tau}1B(0)^{1} = \Big[{}_{\tau}1B(0)\circ\overline{(-\mathrm{BIAS}(0)\circ{}_{\tau}B(0))} + {}_{\tau}1E(0)(+\,\mathrm{BIAS}(0))
$$
$$
+ {}_{\tau}1B(-3)\circ\overline{(-\mathrm{BIAS}(-3)\circ{}_{\tau}B(-3))} + {}_{\tau}1E(-3)(+\,\mathrm{BIAS}(-3)\Big]\Big[\overleftarrow{{}_{\tau}1B}\ \mathrm{ENABLE}\Big]
$$

$$
{}_{\tau}2A(0)^{1} = \Big[{}_{\tau}2A(0)\circ\overline{(+\,\mathrm{BIAS}(0)\circ{}_{\tau}A(0))} + {}_{\tau}2E(0)(-\mathrm{BIAS}(0))
$$
$$
+ {}_{\tau}2A(-3)\circ\overline{(+\,\mathrm{BIAS}(-3)\circ{}_{\tau}A(-3))} + {}_{\tau}2E(-3)(-\mathrm{BIAS}(-3))\Big]\Big[\overleftarrow{{}_{\tau}2A}\ \mathrm{ENABLE}\Big]
$$

$$
{}_{\tau}2B(0)^{1} = \Big[{}_{\tau}2B(0)\circ\overline{(-\mathrm{BIAS}(0)\circ{}_{\tau}B(0))} + {}_{\tau}2E(0)(+\,\mathrm{BIAS}(0))
$$
$$
+ {}_{\tau}2B(-3)\circ\overline{(-\mathrm{BIAS}(-3)\circ{}_{\tau}B(-3))} + {}_{\tau}2E(-3)(+\,\mathrm{BIAS}(-3))\Big]\Big[\overleftarrow{{}_{\tau}2B}\ \mathrm{ENABLE}\Big]
$$

$$
{}_{\tau}3A(0)^{1} = {}_{\tau}3A(0)\circ\overline{(+\,\mathrm{BIAS}(0)\circ{}_{\tau}A(0))} + {}_{\tau}3E(0)(-\mathrm{BIAS}(0))
$$
$$
+ {}_{\tau}3A(-3)\circ\overline{(+\,\mathrm{BIAS}(-3)\circ{}_{\tau}A(-3))} + {}_{\tau}3E(-3)(-\mathrm{BIAS}(-3))
$$

$$
{}_{\tau}3B(0)^{1} = {}_{\tau}3B(0)\circ\overline{(-\mathrm{BIAS}(0)\circ{}_{\tau}B(0))} + {}_{\tau}3E(0)(+\,\mathrm{BIAS}(0))
$$
$$
+ {}_{\tau}3B(-3)\circ\overline{(-\mathrm{BIAS}(-3)\circ{}_{\tau}B(-3))} + {}_{\tau}3E(-3)(+\,\mathrm{BIAS}(-3))
$$

$$
P5(0)^{1} = \Big[P5(0) + P5(-3)\Big]\Big[\overleftarrow{P5}\ \mathrm{ENABLE}\Big]
$$

$$
M5(0)^{1} = \Big[M5(0) + M5(-3)\Big]\Big[\overleftarrow{M5}\ \mathrm{ENABLE}\Big]
$$

NOTES:

1) ${}_{\tau}1E = {}_{\tau}1EA + {}_{\tau}1EB$

${}_{\tau}2E = {}_{\tau}2EA + {}_{\tau}2EB$

${}_{\tau}3E = {}_{\tau}3EA + {}_{\tau}3EB$

2) "ENABLE" signals are valid from the time that two consecutive tracks with Range Correlation are obtained until two consecutive tracks are missed.

AVOID-II

INTERMEDIATE DISPLAY LOGIC

FIGURE 7

COMMAND DISPLAY LOGIC

$$\text{LVS} \quad +500 = P5(0)^1 + T1A(0)^1 + T2A(0)^1 + T3A(0)^1$$

$$\text{DIVE} = T1A(0)^1 \cdot \overline{T1B(0)}^1$$

$$\text{LEVEL} = T1A(0)^1 \cdot T1B(0)^1$$

$$\text{CLIMB} = \overline{T1A(0)}^1 \cdot T1B(0)^1$$

$$\text{LVS} \quad -500 = M5(0)^1 + T1B(0)^1 + T2B(0)^1 + T3B(0)^1$$

RANGE LIGHT DISPLAY LOGIC

$$\text{FLASHING ABOVE RANGE LIGHT} = [T1A(0)^1 + T2A(0)^1] \cdot [(T1A(0) + T2A(0)) \cdot (\text{UPDATE}) + \overline{(T1A(0) + T2A(0)} \cdot \overline{\text{UPDATE}}]$$

$$\text{FLASHING BELOW RANGE LIGHT} = [T1B(0)^1 + T2B(0)^1] \cdot [(T1B(0) + T2B(0)) \cdot (\text{UPDATE}) + \overline{(T1B(0) + T2B(0))} \cdot \overline{\text{UPDATE}}]$$

$$\text{CONTINUOUS ABOVE RANGE LIGHT} = [T3A(0)^1] \cdot [T3A(0) \cdot (\text{UPDATE} + \overline{T3A(0)}) \cdot \overline{\text{UPDATE}}]$$

$$\text{CONTINUOUS BELOW RANGE LIGHT} = [T3B(0)^1] \cdot [T3A(0) \cdot (\text{UPDATE} + \overline{T3B(0)}) \cdot \overline{\text{UPDATE}}]$$

Notes: "1" Indicates an output from the Intermediate Display Logic

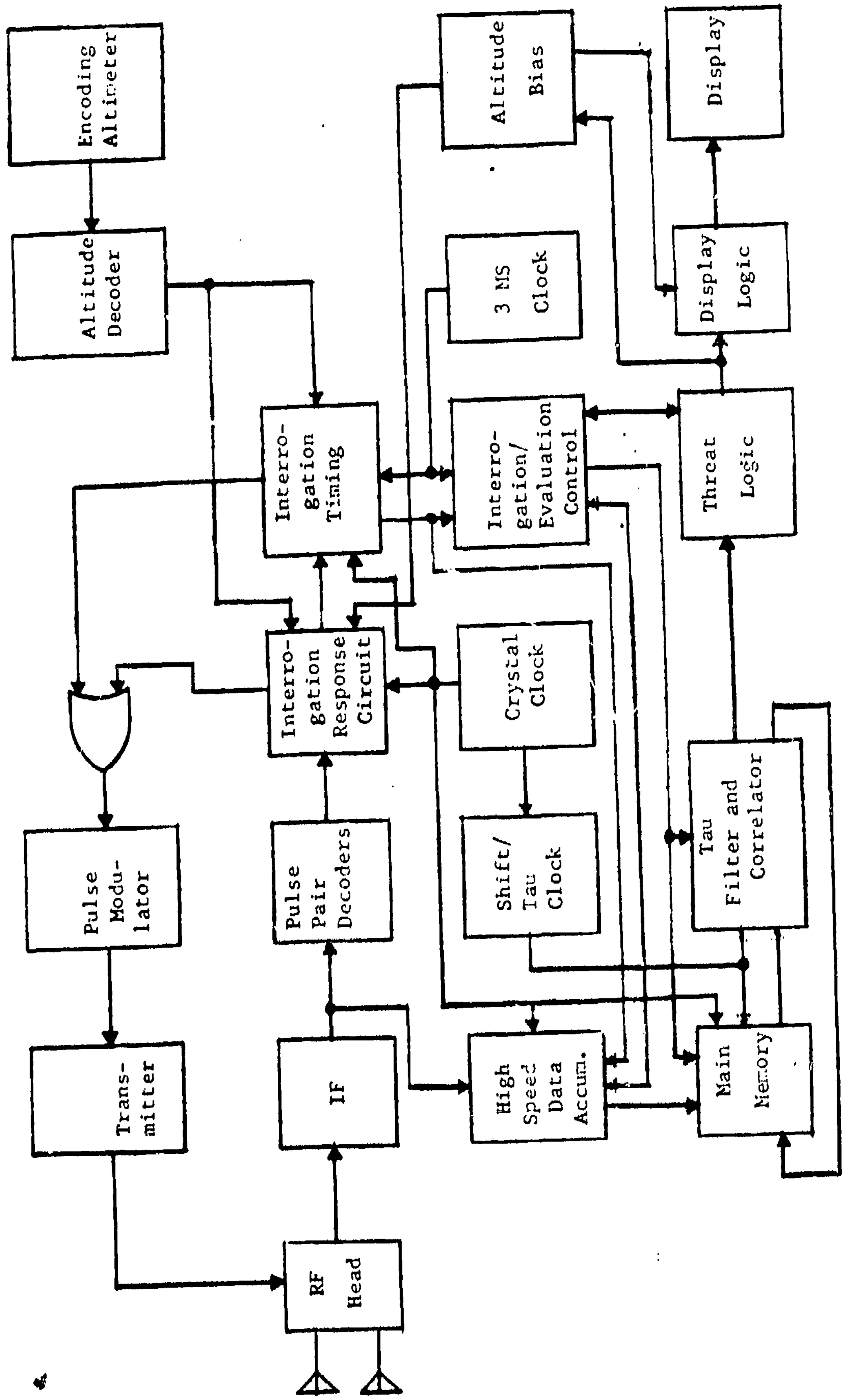
UPDATE Display latest range data

$\overline{\text{UPDATE}}$ Do not change range display

AVOID-II

DISPLAY LOGIC

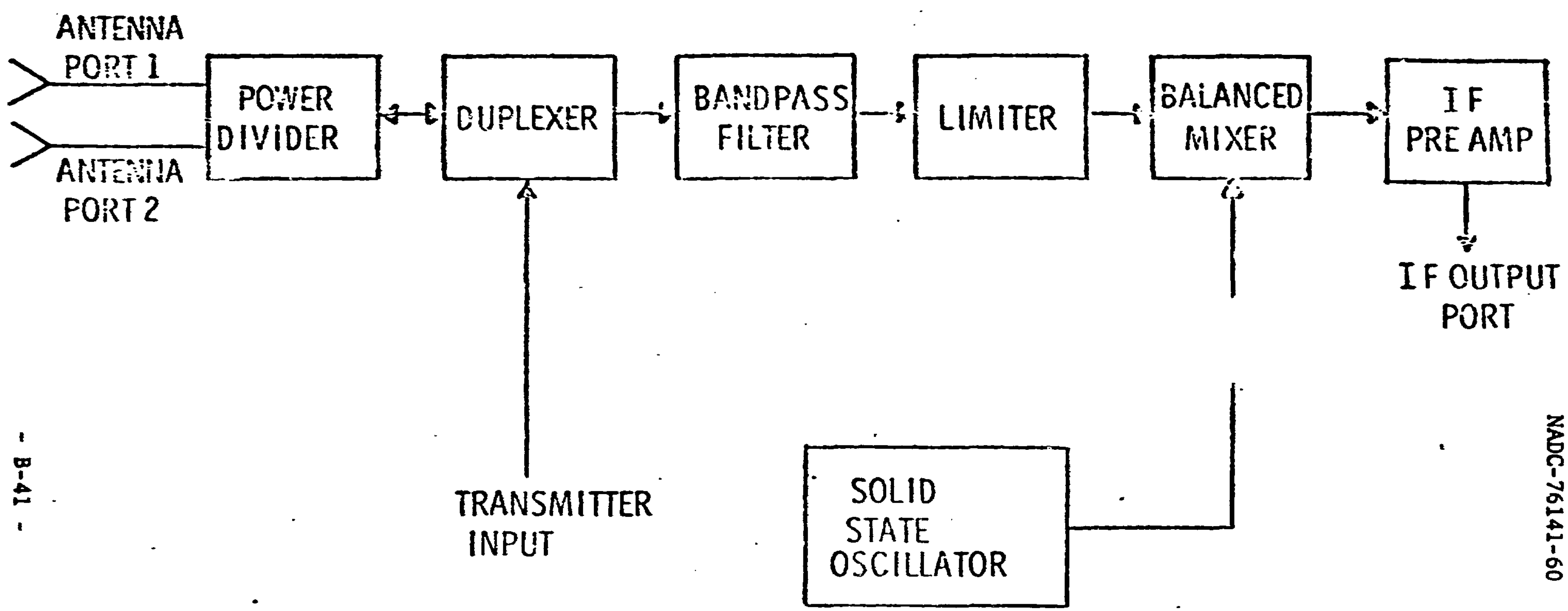
FIGURE 8



AVOID-II

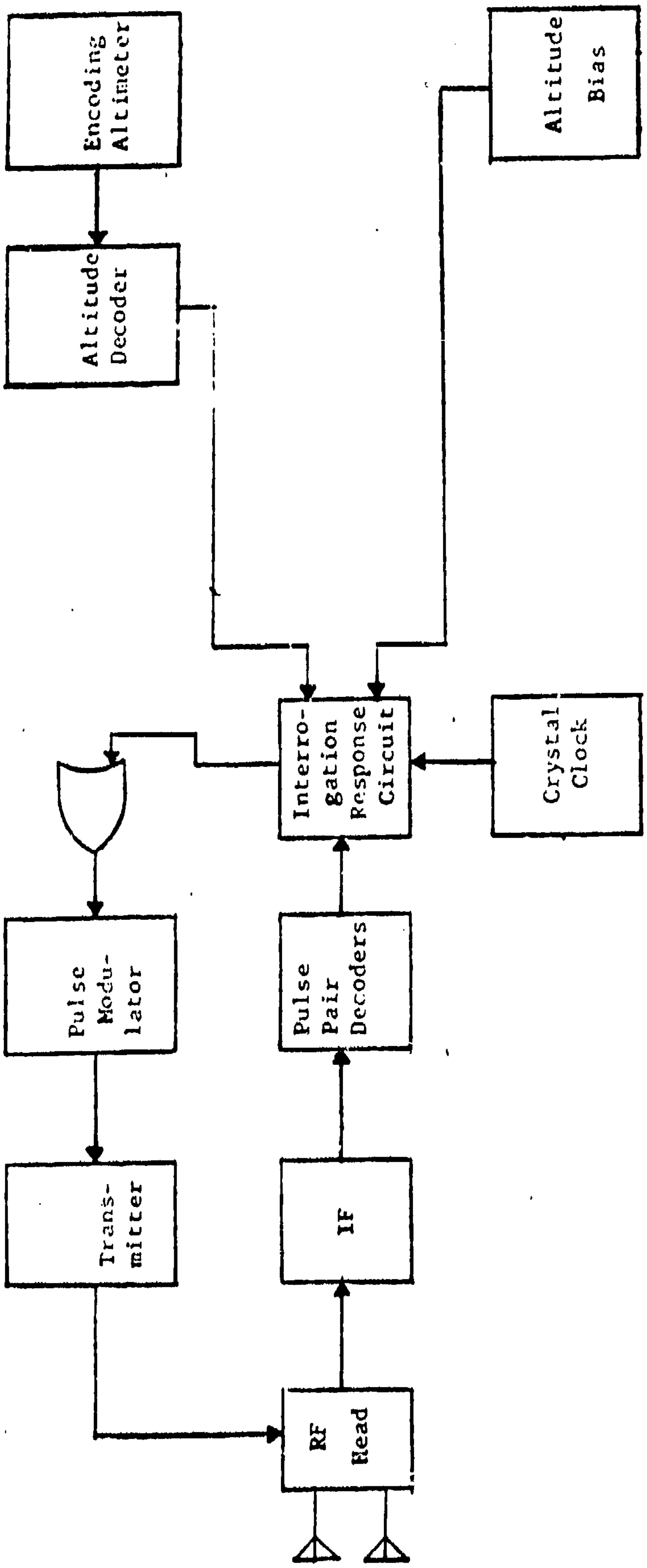
BLOCK DIAGRAM

FIGURE 9

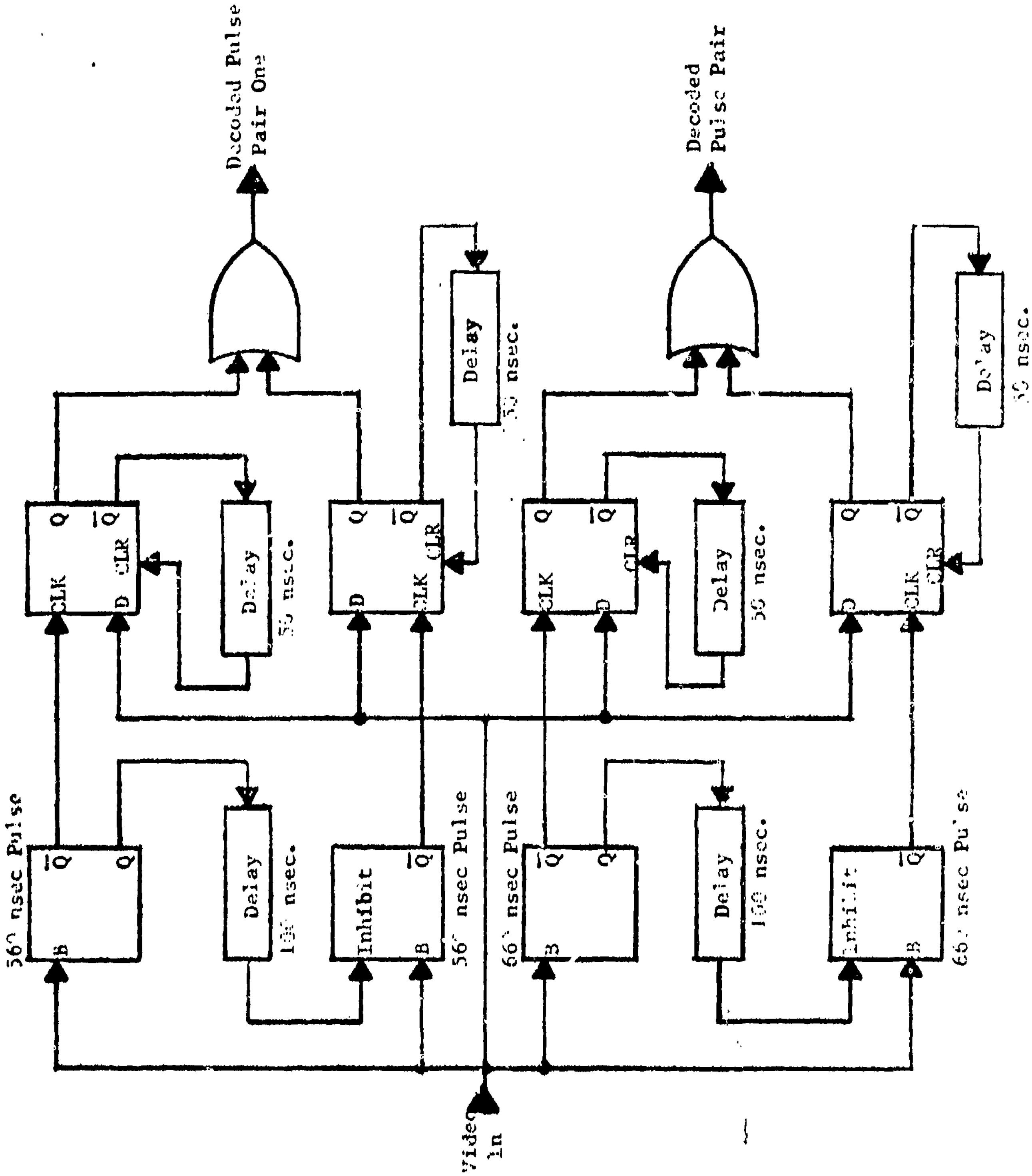


AVOID-II
RF HEAD

FIGURE 10

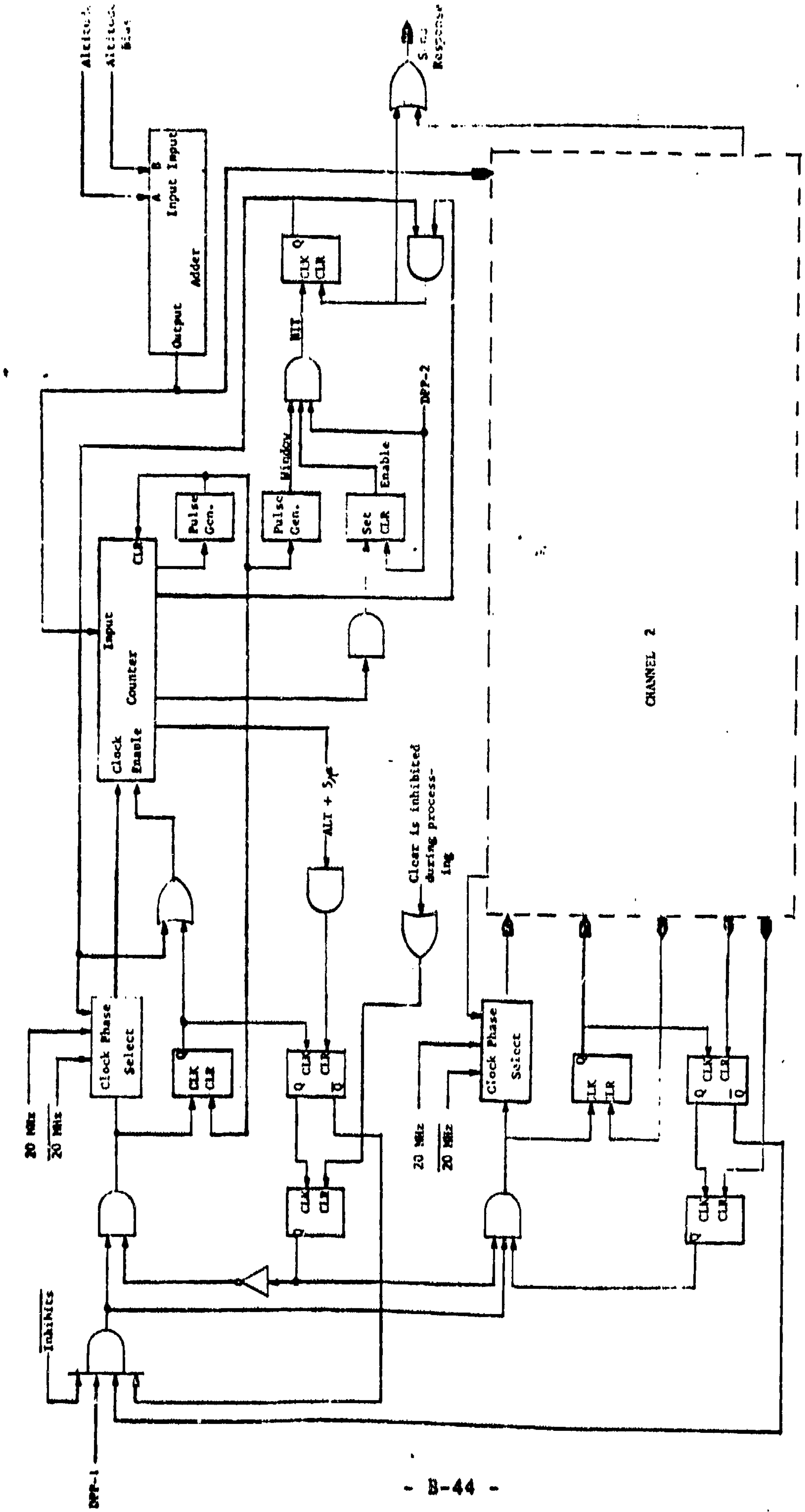


AVOID-II
LOCK DIAGRAM (RESPONSE)
FIGURE 11



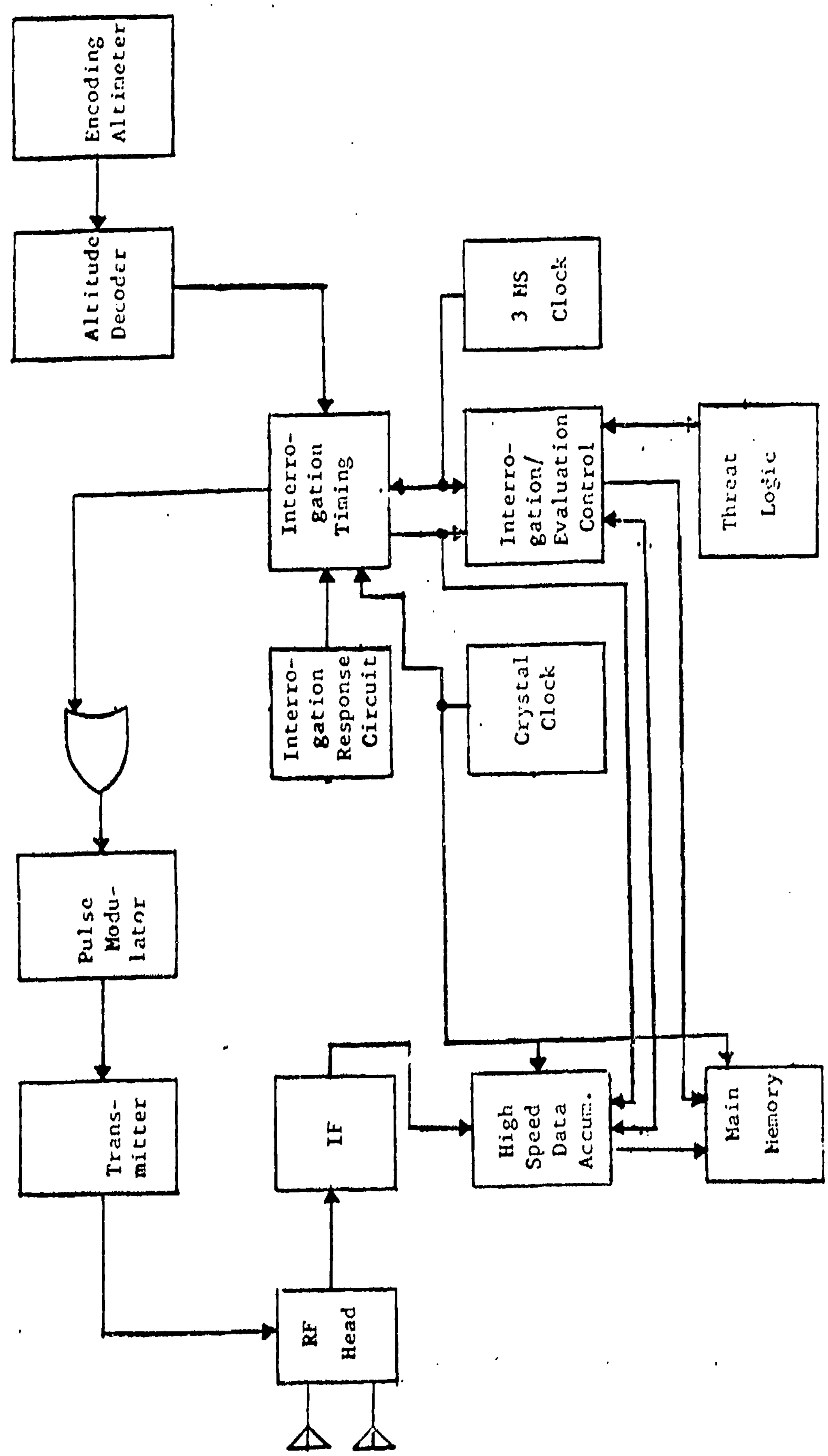
AVOID-II
DUAL PULSE PAIR DECODERS

FIGURE 12



AVOID-II
INTERROGATION RESPONSE

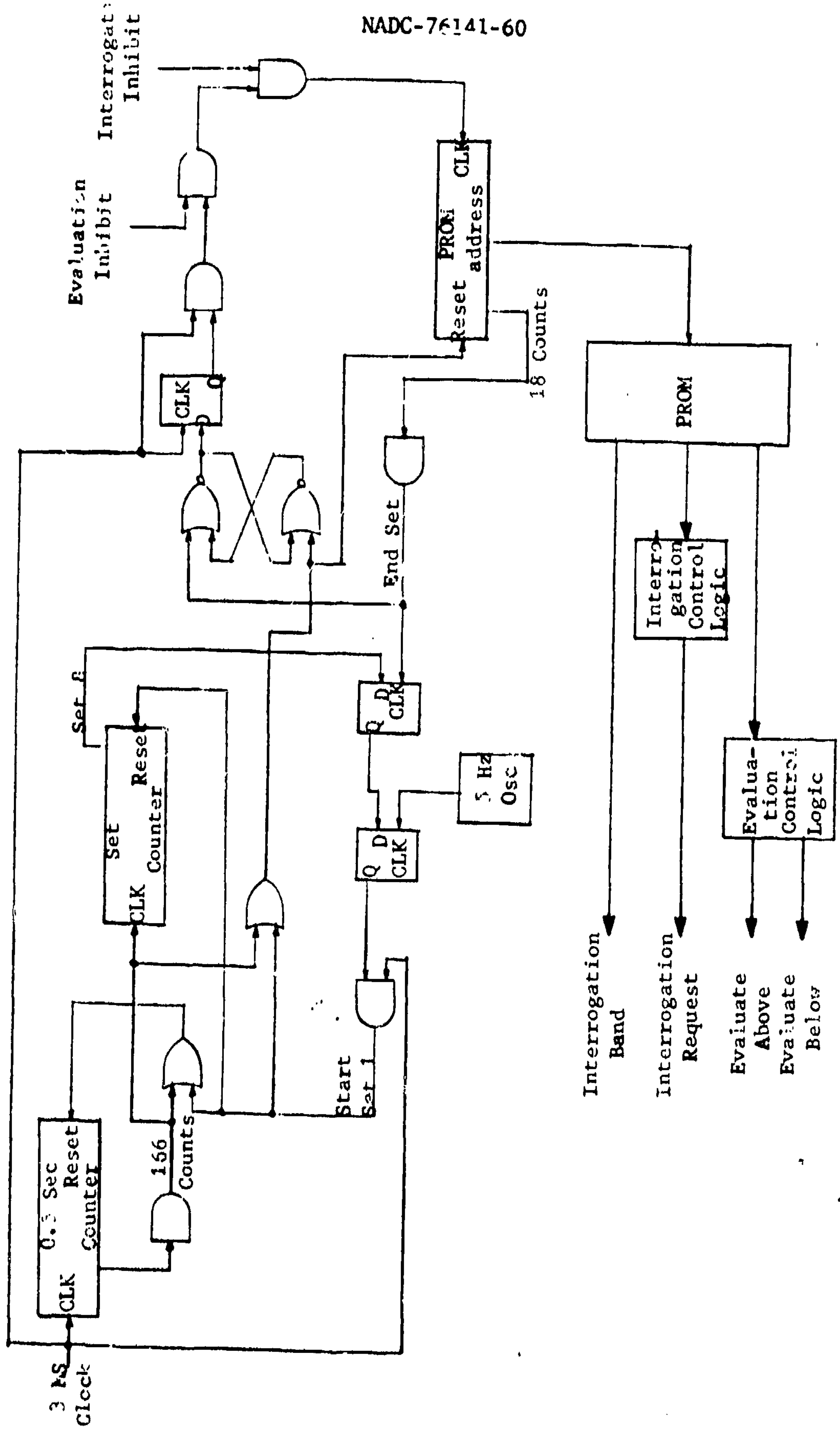
FIGURE 13



AVOID-II

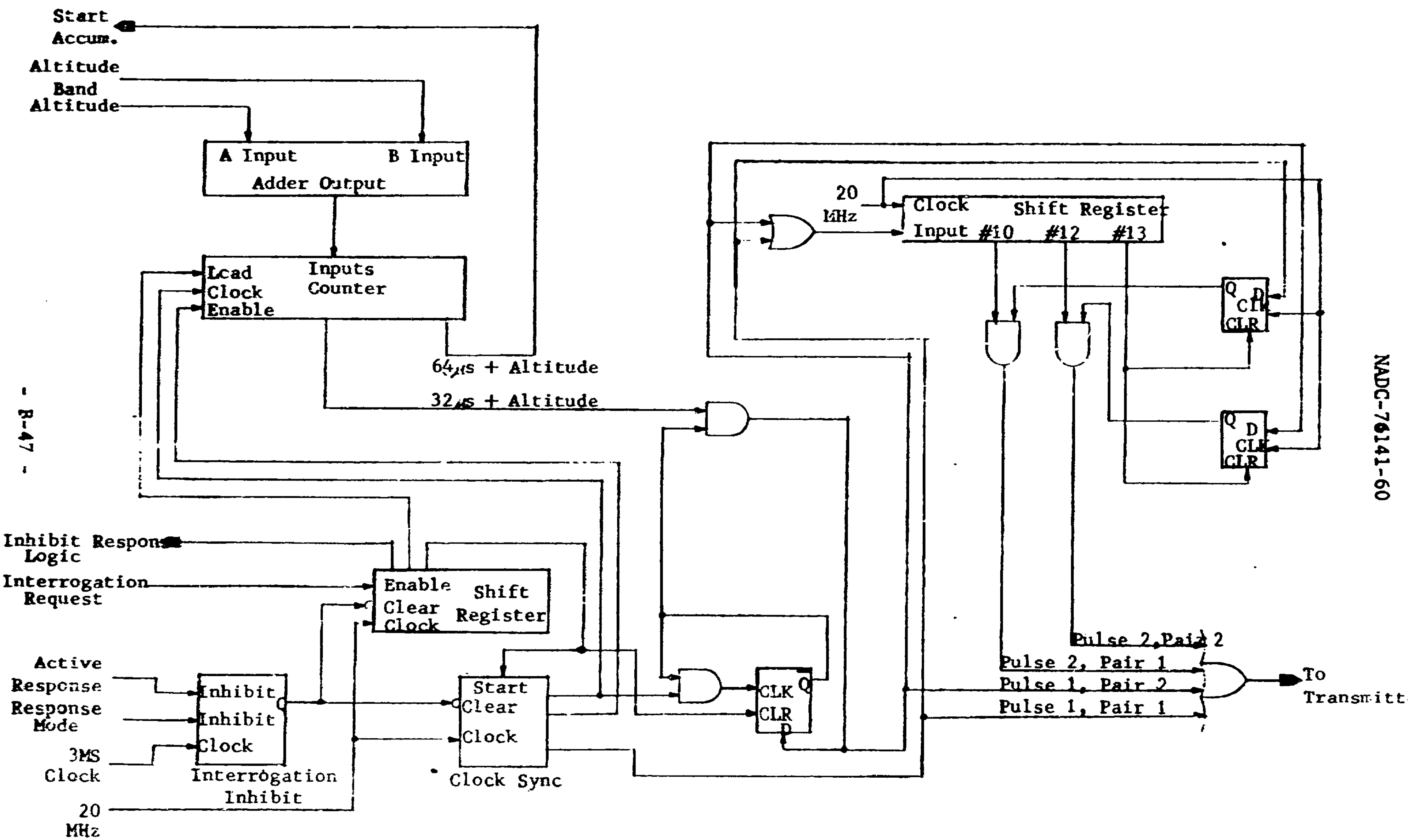
BLOCK DIAGRAM (INTERROGATIONS)

FIGURE 14



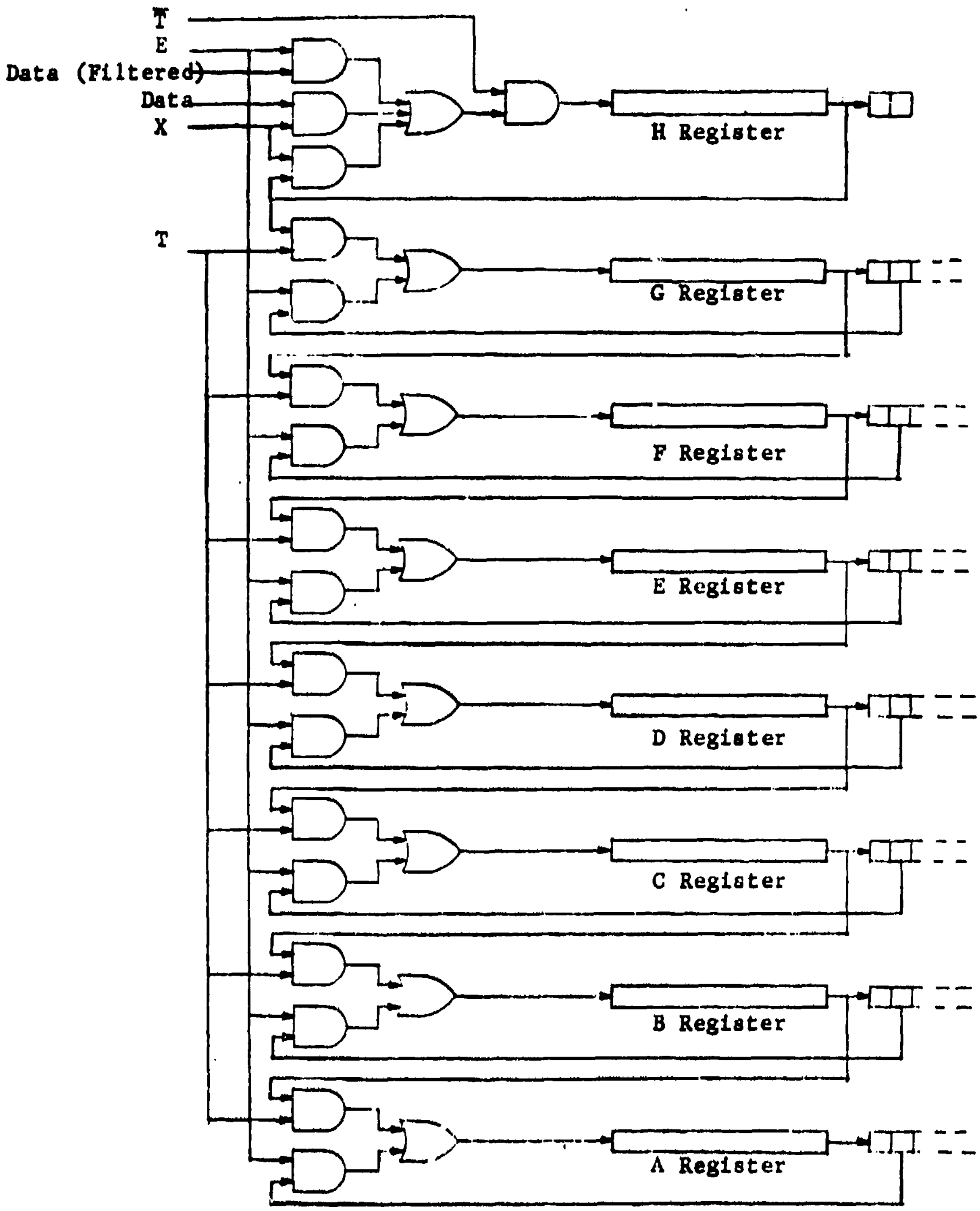
AVOID-II
INTERROGATION/EVALUATION CONTROL

FIGURE 15



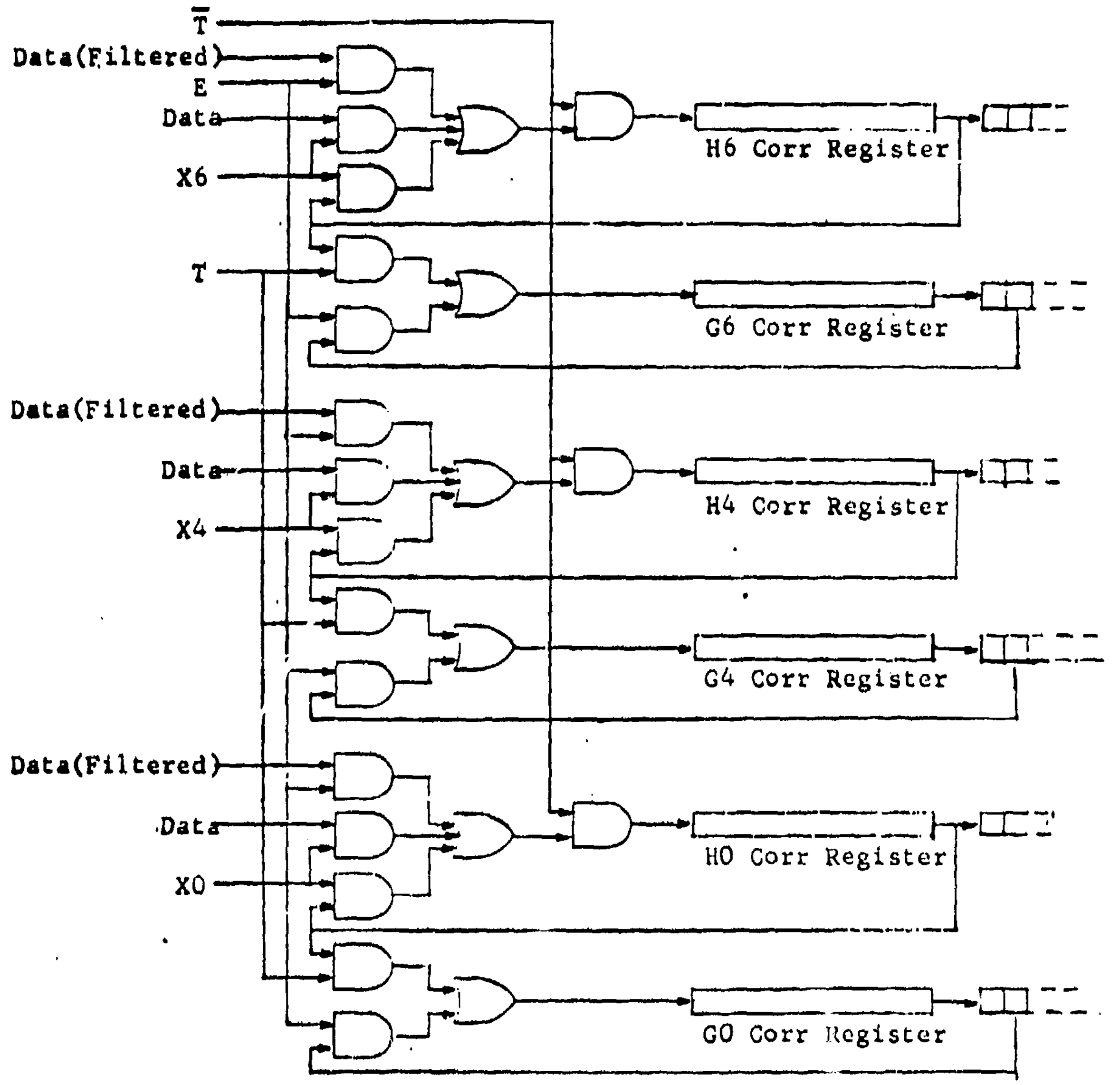
AVOID-II
INTERROGATION TIMING

FIGURE 16



Code T = Translate
T̄ = Translate Not
E - Evaluate
X = Transfer
Data = Data from High Speed Data Accumulator
Data (Filtered) = H Register Data through Tau Filter

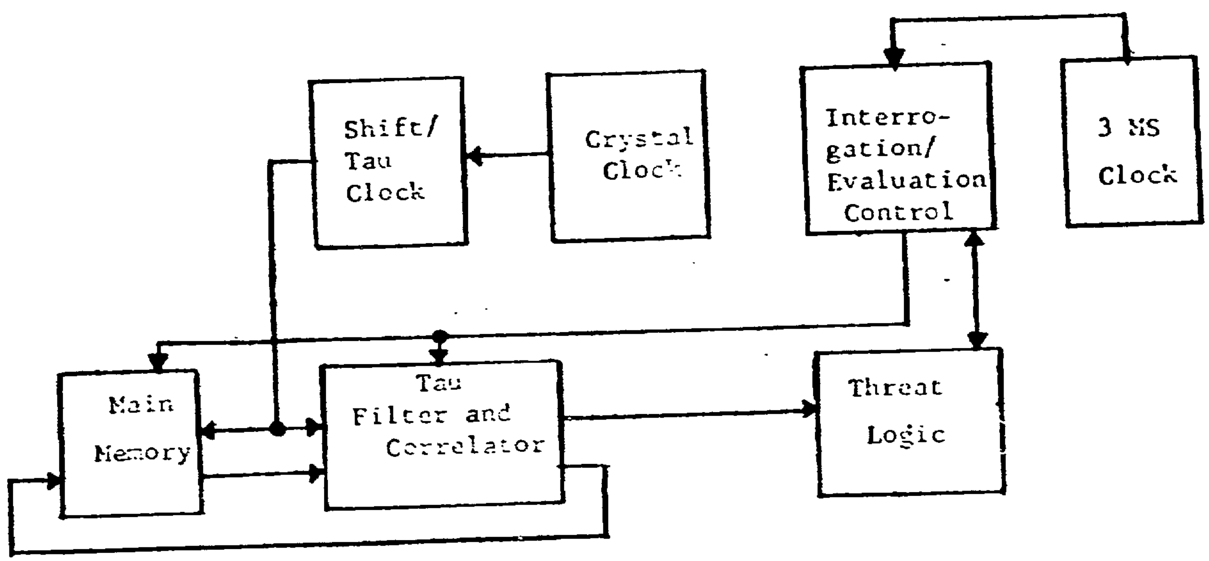
AVOID-II
RANGE DATA STORAGE REGISTERS
FIGURE 17



T = Translate
T̄ = Translate (Not)
E = Evaluate
Data = Data from High Speed Data Accumulator (HSDA)
Data (Filtered) = Data filtered by Tau Filter
X6 = Transfer 600 foot Data from HSDA
X4 = Transfer 400 foot Data from HSDA
X0 = Transfer zero foot Data from HSDA

AVOID-II
ALTITUDE CORRELATION REGISTERS

FIGURE 18



AVOID-II

BLOCK DIAGRAM (EVALUATION)

FIGURE 19

REGISTERS SHIFTED

Ai	1	1	1	1	1	1	1
Bi	1		1	1	1	1	1
Ci		1	1		1	1	1
Di		1		1	1		1
Ei		1			1		1
Fi				1			1
Gi						1	
Hi							
	$\phi 1$	$\phi 2$	$\phi 3$	$\phi 4$	$\phi 5$	$\phi 6$	$\phi 7$

CLOCK PHASE

AVO[illegible]

TAU CLOCK

FIGURE 20

INTRUDER EQUATION

$$
\begin{aligned}
(I) = {} & H_i[G_{i+1} + G_i + G_{i-1}] \cdot [F_{i+1} + F_i + F_{i-1}] \cdot \\
& [E_{i+1} + E_i + E_{i-1}] \cdot [D_{i+1} + D_i + D_{i-1}] \cdot \\
& [C_{i+1} + C_i + C_{i-1}] \cdot [B_{i+1} + B_i + B_{i-1}] \cdot A_i + \\
& H_i[G_{i+2} \cdot \overline{\emptyset}_1 \cdot \overline{\emptyset}_6 \cdot \overline{\emptyset}_7 + G_{i+1} + G_i] \cdot \\
& [F_{i+2} + F_{i+1} + F_i] \cdot [E_{i+2} + E_{i+1} + E_i] \cdot \\
& [D_{i+2} + D_{i+1} + D_i] \cdot [C_{i+2} + C_{i+1} + C_i] \cdot \\
& [B_{i+2} \cdot \emptyset_1 \cdot \overline{\emptyset}_6 \cdot \overline{\emptyset}_7 + B_{i+1} + B_i] \cdot A_i
\end{aligned}
$$

CORRELATION EQUATIONS

$$
\begin{aligned}
H(6) = {} & H_i \cdot [H_{i+1} + H_i + H_{i-1}]^6 \cdot \\
& [G_{i+2} \cdot [G_{i+3} + G_{i+2} + G_i]^6 + G_{i+1} \cdot [G_{i+2} + G_{i+1} + G_i]^6 \\
& + G_i \cdot [G_{i+1} + G_i + G_{i-1}]^6 + G_{i-1}[G_i + G_{i-1} + G_{i-2}]^6]
\end{aligned}
$$

$$
\begin{aligned}
H(4) = {} & H_i \cdot [H_{i+1} + H_i + H_{i-1}]^4 \cdot \\
& [G_{i+2} [G_{i+3} + G_{i+2} + G_i]^4 + G_{i+1}[G_{i+2} + G_{i+1} + G_i]^4 \\
& + G_i[G_{i+1} + G_i + G_{i-1}]^4 + G_{i-1}[G_i + G_{i-1} + G_{i-2}]^4
\end{aligned}
$$

$$
\begin{aligned}
H(0) = {} & H_i[H_{i+1} + H_i + H_{i-1}]^{\circ} \\
& [G_{i+2}[G_{i+3} + G_{i+2} + G_{i+1}]^{\circ} + G_{i+1}[G_{i+2} + G_{i+1} + G_i]^{\circ} \\
& + G_i[G_{i+1} + G_i + G_{i-1}]^{\circ} + G_{i-1}[G_i + G_{i-1} + G_{i-2}]^{\circ}
\end{aligned}
$$

AVOID-II
INTRUDER AND CORRELATION EQUATIONS
FIGURE 21

Interrogate I(+6)

$$T1A = T1(+6) \cdot [H(0) + H(+4)] \cdot \overline{H(-6)}$$

$$T2A = T2(+6) \cdot [H(0) + H(+4)] \cdot \overline{H(-6)}$$

$$T3A = T3(+6) \cdot [H(0) + H(+4)] \cdot \overline{H(-6)}$$

$$TA = [T1(+6) + T2(+6) + T3(+6)] \cdot H(+4) \cdot \overline{H(-6)}$$

$$T1EA = T1(+6) \cdot H\ (-6) \cdot [H(0) + H(+4)]$$

$$T2EA = T2(+6) \cdot H\ (-6) \cdot [H(0) + H(+4)]$$

$$T3EA = T3(+6) \cdot H\ (-6) \cdot [H(0) + H(+4)]$$

$$P5 = [T1(+6) + T2(+6) + T3(+6)] \cdot \overline{H(0)}$$

Interrogate I(-6)

$$T1B = T1(-6) \cdot [H(0) + H(-4)] \cdot \overline{H(+6)}$$

$$T2B = T2(-6) \cdot [H(0) + H(-4)] \cdot \overline{H(+6)}$$

$$T3B = T3(-6) \cdot [H(0) + H(-4)] \cdot \overline{H(+6)}$$

$$TB = [T1(+6) + T2(+6) + T3(+6)] \cdot H(-4) \cdot \overline{H(+6)}$$

$$T1EB = T1(-6) \cdot H\ (+6) \cdot [H(0) + H(-4)]$$

$$T2EB = T2(-6) \cdot H\ (+6) \cdot [H(0) + H(-4)]$$

$$T3EB = T3(-6) \cdot H\ (+6) \cdot [H(0) + H(-4)]$$

$$M5 = [T1(-6) + T2(-6) + T3(-6)] \cdot \overline{H(0)}$$

AVOID-II
THREAT EQUATIONS

FIGURE 22

$$P5\ \text{Enable}\ (0) = [P5(0) + P5(-3)] \cdot [P\ \text{Enable}\ (-3)] + [P5^{a}_{n}(0)] \cdot [P5^{h}_{n-1}(-3) + P5^{h}_{n}(-3) + P5^{h}_{n+1}(-3) + \ldots + P5^{h}_{n+8}(-3) + P5^{h}_{n+9}(-3)]$$

$$T1A\ \text{Enable}\ (0) = [T1A(0) + T1A(-3)] \cdot [T1A\ \text{Enable}\ (-3)] + [T1A^{a}_{n}(0)] \cdot [T1A^{h}_{n-1}(-3) + T1A^{h}_{n}(-3) + T1A^{h}_{n+1}(-3) + \ldots + T1A^{h}_{n+8}(-3) + T1A^{h}_{n+9}(-3)]$$

$$T2A\ \text{Enable}\ (0) = [T2A(0) + T2A(-3)] \cdot [T2A\ \text{Enable}(-3)] + [T2A^{a}_{n}(0)] \cdot [T2A^{h}_{n-1}(-3) + T2A^{h}_{n}(-3) + T2A^{h}_{n+1}(-3) + \ldots + T2A^{h}_{n+8}(-3) + T2A^{h}_{n+9}(-3)]$$

$$M5\ \text{Enable}\ (0) = [M5(0) + M5(-3)] \cdot [M5\ \text{Enable}(-3)] + [M5^{a}_{n}(0)] \cdot [M5^{h}_{n-1}(-3) + M5^{h}_{n}(-3) + M5^{h}_{n+1}(-3) + \ldots + M5^{h}_{n+8}(-3) + M5^{h}_{n+9}(-3)]$$

$$T1B\ \text{Enable}(0) = [T1B(0) + T1B(-3)] \cdot [T1B\ \text{Enable}(-3)] + [T1B^{a}_{n}(0)] \cdot [T1B^{h}_{n-1}(-3) + T1B^{h}_{n}(-3) + T1B^{h}_{n+1}(-3) + \ldots + T1B^{h}_{n+8}(-3) + T1B^{h}_{n+9}(-3)]$$

$$T2B\ \text{Enable}\ (0) = [T2B(0) + T2B(-3)] \cdot [T2B\ \text{Enable}(-3)] + [T2B^{a}_{n}(0)] \cdot [T2B^{a}_{n-1}(-3) + T2B^{h}_{n}(-3) + T2B^{a}_{n+1}(-3) + \ldots + T2B^{h}_{n+8}(-3) + T2B^{h}_{n+9}(-3)]$$

Where (0) Indicates present sequence

(-3) Indicates previous sequence

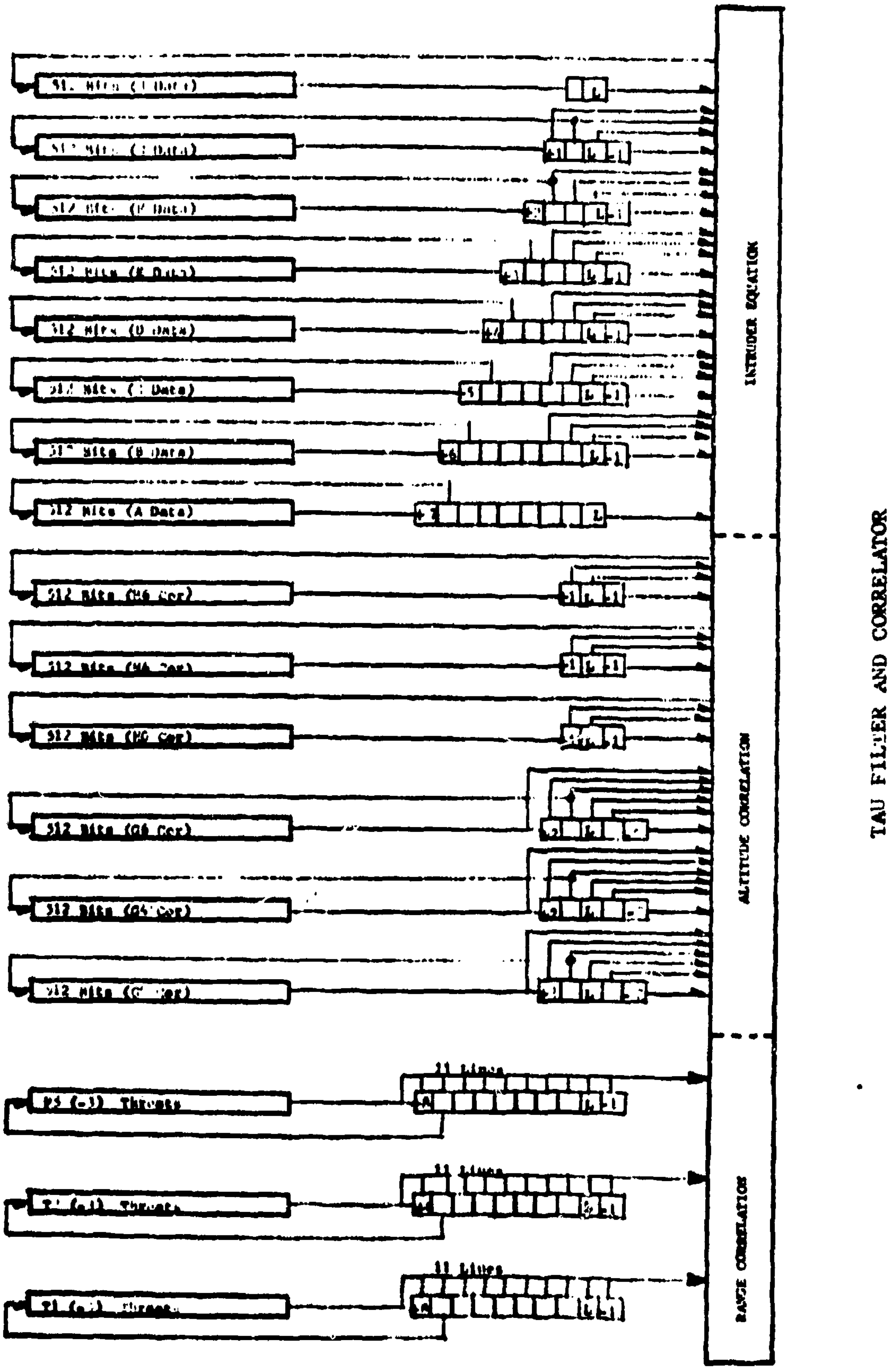
Superscript Indicates set number

Subscript Indicates bin number

Example: $T2A^{h}_{n-5}(-3)$ is a Tau 2 Above threat which, in the previous sequence, had H Set data in bin number n-5.

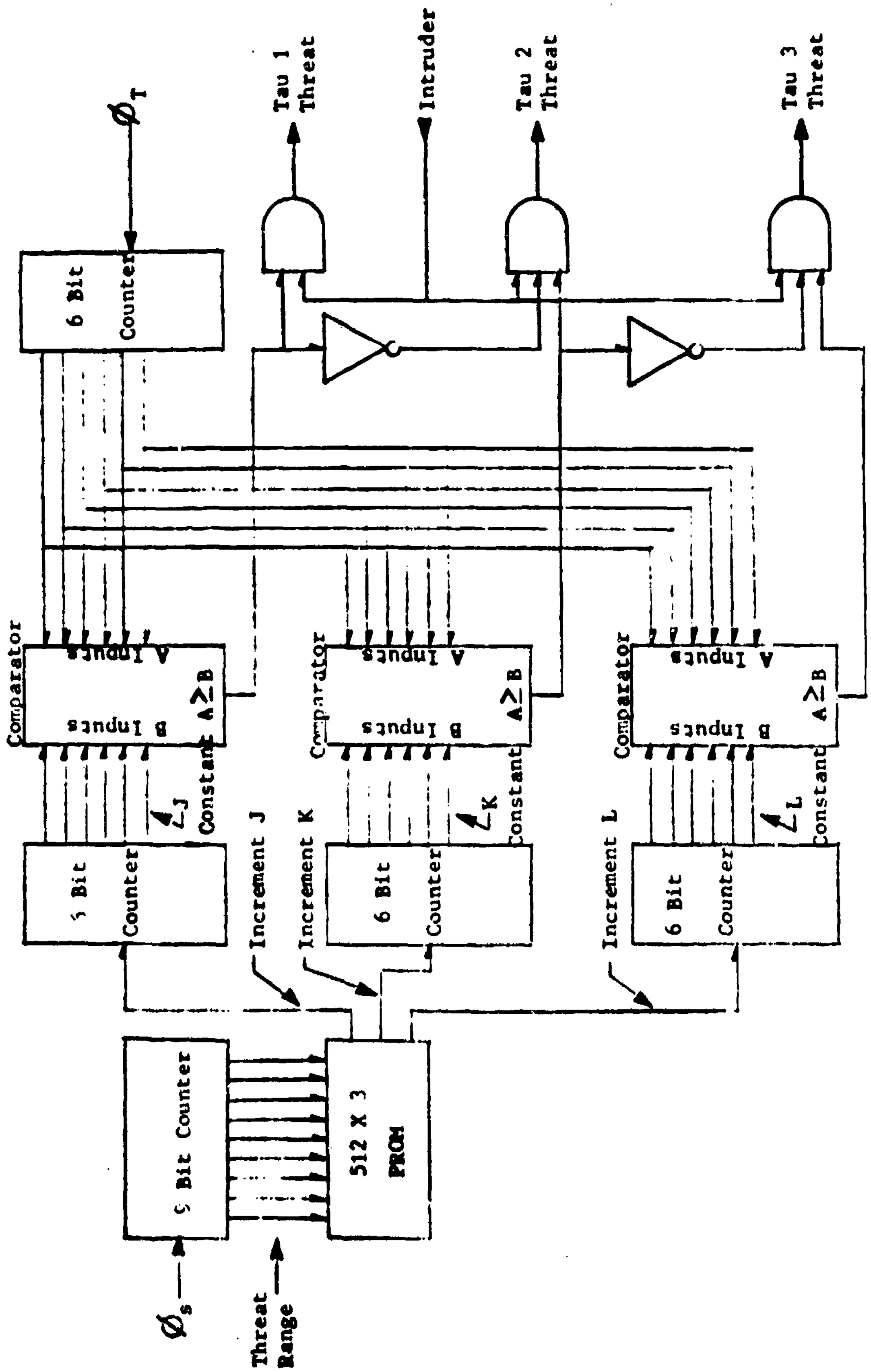
AVOID-II
RANGE CORRELATION EQUATIONS

FIGURE 23



AVOID-II
TAU FILTER INPUT

FIGURE 24



AVOID-II
THREAT CONSTANT MECHANIZATION

FIGURE 25

THREAT	ALTITUDE ZONE	TAU ZONE
P5	700 to 1200	1 or 2 or 3
T1A	100 to 600	1
T2A	100 to 600	2
T3A	100 to 600	3
TA	100 to 400	1 or 2 or 3
T1EA[1]	0	1
T2EA[1]	0	2
T3EA[1]	0	3
T3EB[2]	0	3
T2EB[2]	0	2
T1EB[2]	0	1
TB	-400 to -100	1 or 2 or 3
T3B	-600 to -100	3
T2B	-600 to -100	2
T1B	-600 to -100	1
M5	-1200 to -700	1 or 2 or 3

T1E=T1EA+T1EB

T2E=T2EA+T2EB

T3E=T3EA+T3EB

TEAA=T1EA+T2EA+T3EA

TEAB=T1EB+T2EB+T3EB

TE=TEAA+TEAB

Notes 1) Threats determined during evaluation of the Above Band

2) Threats determined during evaluation of the Below Band

3) Altitudes are encoded altitudes

AVOID II

THREAT DEFINITIONS

FIGURE 26

	-bias (0)				0bias (0)				+bias (0)			
τEAA τEAB \ τAτB	00	01	11	10	00	01	11	10	00	01	11	10
-bias (0+)												
00	D	0	0	1	0	0	0	1	0	0	0	$\overline{1/2}$
01	1	0	0	1	0	0	0	1	0	0	0	0
11	1	0	0	1	$\overline{1/2}$	0	0	1	0	0	0	0
10	1	0	0	1	1	0	0	1	0	0	0	1
0 bias (0+)												
00	$\overline{D}$	$\overline{1/2}$	1	0	1	0	1	0	$\overline{D}$	0	1	1/2
01	0	0	1	0	0	0	1	0	0	0	1	1
11	0	1	1	0	0	0	1	0	0	0	1	1
10	0	1	1	0	0	0	1	0	0	0	1	0
+bias (0+)												
00	0	1/2	0	0	0	1	0	0	D	1	0	0
01	0	1	0	0	1	1	0	0	1	1	0	0
11	0	0	0	0	1/2	1	0	0	1	1	0	0
10	0	0	0	0	0	1	0	0	1	1	0	0

NOTES: D = τEAA(0) + τEAB(0) + τA(0) + τB(0)
τA = τA(100 to 400 ft)
τB = τB(-100 to -400 ft)

AVOID-II
ALTITUDE BIAS LOGIC

FIGURE 27

AVOID-II

TAU ZONE 1 - THREAT EVALUATION

RANGE INTERVAL	THREAT CRITERIA	$\dot{R}$ DESIRED	$\dot{R}$ MINIMUM	$\dot{R}$ REJECT
0 - 2150	L-6	-	-	-
2150-2200	L-5	-88	-94	-63
2200-2250	L-4	-74	-80	-49
2250-2300	L-3	-61	-66	-34
2300-2350	L-2	-47	-51	-20
2350-2400	L-1	-34	-37	-6
2400-2450	L	-20	-23	9
2450-2500	L+1	-7	-9	23
2500-2550	L+2	7	6	37
2550-2600	L+3	20	20	51
2600-2650	L+4	34	34	66
2650-2700	L+5	47	49	80
2700-2750	L+6	61	63	94
2750-2900	L+7	98	77	109
2900-3300	L+8	108	91	123
3300-3750	L+9	123	106	137
3750-4200	L+10	139	120	151
4200-4600	L+11	153	134	166
4600-5050	L+12	168	149	180
5050-5500	L+13	184	163	194
5500-5950	L+14	199	177	209
5950-6350	L+15	214	191	223
6350-6800	L+16	229	206	237
6800-7250	L+17	245	220	251
7250-7700	L+18	260	234	266
7700-8150	L+19	276	249	280
8150-8600	L+20	292	263	294
8600-9000	L+21	307	277	309
9000-9450	L+22	321	291	323
9450-9900	L+23	337	306	337
9900-10,350	L+24	353	320	351
10,350-10,750	L+25	368	334	366

/Cont'd...

TAU ZONE 1 - THREAT EVALUATION(CONTINUED)

RANGE INTERVAL	THREAT CRITERIA	Ṙ DESIRED	Ṙ MINIMUM	Ṙ REJECT
10,750-11,200	L+26	382	349	380
11,200-11,650	L+27	398	363	394
11,650-12,050	L+28	413	377	409
12,050-12,500	L+29	428	391	423
12,500-12,950	L+30	443	406	437
12,950-13,350	L+31	458	420	451
13,350-13,800	L+32	473	434	466
13,800-14,250	L+33	489	449	480
14,250-14,700	L+34	504	463	494
14,700-15,100	L+35	519	477	509
15,100-15,550	L+36	534	491	523
15,550-16,000	L+37	550	506	537
16,000-16,400	L+38	564	520	551
16,400-16,850	L+39	579	534	566
16,850-17,300	L+40	595	549	580
17,300-17,700	L+41	610	563	594
17,700-18,150	L+42	625	577	609
18,150-18,600	L+43	640	591	623
18,600-19,050	L+44	656	606	637
19,050-19,450	L+45	671	620	651
19,450-19,900	L+46	686	634	666
19,900-20,350	L+47	701	649	680
20,350-20,750	L+48	716	663	694
20,750-21,200	L+49	731	677	709
21,200-21,650	L+50	747	691	723
21,650-22,100	L+51	762	706	737
22,100-22,550	L+52	778	720	751
22,550-24,850	L+53	826	734	766
24,850-25,600	L+54	-	-	-

TABLE 1

TAU ZONE 2 - THREAT EVALUATION

RANGE INTERVAL	THREAT CRITERIA	$\dot{R}$ DESIRED	$\dot{R}$ MINIMUM	$\dot{R}$ REJECT
2600-6100	L+3	50	20	51
6100-6150	L+4	50	34	66
6150-6200	L+5	50	49	80
6200-6250	L+6	61	63	94
6250-6300	L+7	74	77	109
6300-6350	L+8	88	91	123
6350-6400	L+9	101	106	137
6400-6450	L+10	147	120	151
6450-6950	L+11	153	134	166
6950-7600	L+12	166	149	180
7600-8250	L+13	181	163	194
8250-8900	L+14	196	177	209
8900-9550	L+15	211	191	223
9550-10,200	L+16	226	206	237
10,200-10,850	L+17	241	220	251
10,850-11,500	L+18	256	234	266
11,500-12,150	L+19	271	249	280
12,150-12,800	L+20	285	263	294
12,800-13,450	L+21	300	277	309
13,450-14,100	L+22	315	291	323
14,100-14,750	L+23	330	306	337
14,750-15,400	L+24	345	320	351
15,400-16,050	L+25	360	334	366
16,050-16,700	L+26	375	349	380
16,700-17,350	L+27	390	363	394
17,350-18,000	L+28	404	377	409
18,000-18,650	L+29	419	391	443
18,650-19,300	L+30	434	406	437
19,300-19,950	L+31	449	420	451
19,950-20,600	L+32	464	434	466
20,600-21,250	L+33	479	449	480
21,250-21,900	L+34	494	463	494
21,900-22,550	L+35	509	477	509

TAU ZONE 2 - THREAT EVALUATION (CONTINUED)

RANGE INTERVAL	THREAT CRITERIA	$\dot{R}$ DESIRED	$\dot{R}$ MINIMUM	$\dot{R}$ REJECT
22,550-23,200	L+36	523	491	523
23,200-23,950	L+37	538	506	537
24,250-25,600	-	-	-	-

TABLE 2

AVOID-II

TAU ZONE 3 - THREAT EVALUATION

RANGE INTERVAL	THREAT CRITERIA	$\dot{R}$ DESIRED	$\dot{R}$ MINIMUM	$\dot{R}$ REJECT
2150-5650	L-6	-	-	-
5650-5700	L-5	-88	-94	-63
5700-5750	L-4	-74	-80	-49
5750-5800	L-3	-61	-66	-34
5800-5850	L-2	-47	-51	-20
5850,5900	L-1	-34	-37	-6
5900-5950	L	-20	-23	9
5950-6000	L+1	-7	-[illegible]	23
6000-6050	L+2	7	6	37

TABLE 3

AVOID-II

AUTOMATIC OPERATION CONTROLS

AIRCRAFT STATUS	INPUTS	INTERROGATION	RESPONSE	THREAT LOGIC
ON GROUND	OLEO STRUT SWITCH CLOSED	NO	NO	(NA)
AFTER TAKEOFF 0-12 SECONDS	OLEO STRUT SWITCH OPEN	NO	YES	(NA)
12-42 SECONDS	OLEO STRUT SWITCH OPEN	YES	YES	INHIBIT: . DIVE
LANDING	LANDING GEAR DOWN & LOCKED SWITCH CLOSED	YES	YES	INHIBIT: . DIVE

TABLE 4

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